ROENTGENOGRAPHIC TECHNIQUE

A Manual for Physicians, Students and Technicians

BY

DARMON ARTELLE RHINEHART

A.M., M.D., F.A.C.R.

PROFESSOR OF ROENTGENOLOGY AND APPLIED ANATOMY, SCHOOL OF MEDICINE, UNIVERSITY OF ARKANSAS; ROENTGENOLOGIST TO ST. VINCENT'S INFIRMARY, MISSOURI PACIFIC HOSPITAL, AND THE ARKANSAS CHILDREN'S HOSPITAL, LITTLE ROCK, ARKANSAS; TRUSTEE, AMERICAN REGISTRY OF X-RAY TECHNICIANS

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PREFACE TO THE THIRD EDITION.

THE author is grateful for the reception accorded the first two editions of this book. He is glad of the opportunity offered by a new edition to revise the text thoroughly and include many of the advances made in the field of roentgenographic technique. Many minor alterations have been made, considerable new material has been introduced, some of the illustrations have been changed, thirty-one new figures have been provided, and the book itself has been increased in size.

The general plan of the book remains unchanged. The technical procedures are based on the thickness and roentgenographic density of parts of the human body. The author is still of the opinion that a technique satisfactory in one laboratory cannot be transferred to another and always give satisfaction. For this reason emphasis is placed on the method of developing a roentgenographic technique by experimental exposures and by charting the results of actual diagnostic exposures. In these ways a technique can be developed in the laboratory and with the equipment with which it is to be used. Some of the technical procedures that require expensive accessory apparatus not found in the average office or hospital laboratory, like kymography and body section roentgenography, have been omitted.

The needs of *x*-ray technicians, those of medical students in classes in roentgenology, and of those physicians doing some roentgenographic work for themselves and their colleagues have been particularly kept in mind.

The author is grateful to Mr. L. C. Niedner and to Mr. Alfred B. Greene for many valuable suggestions. He is particularly happy to acknowledge with gratitude the assistance of Mrs. Z. O. Jennings, R.T., for her capable assistance with the experimental work and the illustrations, and that of his secretary, Mrs. Norma Gaston, for her unflagging zeal in seeing the manuscript through its many changes. Mrs. Jennings and Mrs. Gaston assisted in the same capacities with the first two editions of this book which bespeaks an association that has been long and pleasant. He wishes to thank the publishers, Messrs. Lea & Febiger, for their many courtesies.

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ROENTGENOGRAPHIC TECHNIQUE.

CHAPTER I.

ELECTRICITY AND ELECTRIC CURRENTS.[1]

NINETY-TWO chemical elements, composed of smaller subdivisions called atoms, either free or combined in many different chemical compounds, make up all matter, whether gaseous, liquid, or solid. For a long time it was thought that atoms were the smallest subdivisions of matter and could not be further divided. In recent years a great deal of scientific experimentation has led to the belief that atoms have a definite internal structure, the atoms of each element having a structure characteristic of that particular chemical element.

Each atom has a nucleus composed of particles known as protons and neutrons. Each proton has a unit mass and a unit positive electrical charge; each neutron has a mass equal to that of the proton, but it has no electrical charge. In continuous planetary motion around the nucleus, like the motion of the planets around the sun, there is one or more minute particles called electrons. Each electron has a unit negative electrical charge but a very small mass, a mass $\frac{1}{1840}$ of that of the proton or neutron. The negative electrical charge of the electron is the equal of the positive charge of the proton, but opposite in sign, the two being just sufficient to neutralize each other. In all neutral atoms the positive charges of the nuclei are exactly equal to the negative charges of the electrons.

The element hydrogen has the simplest atomic structure. The commonest hydrogen atom has a single proton in the nucleus, a single electron, and a mass of one (Fig. 1, A). Two other varieties of hydrogen have been found that are known as heavy hydrogen. One kind of heavy hydrogen has one proton and one neutron in the nucleus, a single electron, and a mass of two (Fig. 1, B); the other has one proton and two neutrons in the nucleus, a single electron, and an atomic mass of three (Fig. 1, C). The two rarer forms are known as isotopes of hydrogen. In all three varieties the negative electrical charge of the single electron balances the positive charge of the proton in the nucleus. The chemical properties of the three kinds of hydrogen are the same.

[1] Not more than the simplest outline of the physics of electricity, *x*-ray machines and Roentgen-rays can be included. For a more complete discussion the reader is referred to the books listed in the bibliography at the end of this chapter.

The atoms of the other elements are more complex than those of hydrogen. All of them can be arranged in a table in increasing complexity, called the periodic table of the elements. After hydrogen in this table is helium which is 2, lithium which is 3, beryllium which is 4, and so on to uranium which is 92, the most complex of all. The number of the element in the table is thought to indicate the number of positive electrical charges (protons) in the nucleus of the atom of that element and also the number of electrons. The protons and the neutrons in the nuclei taken together indicate the mass number of the element and assist in the determination of its atomic weight. Isotopes, some stable and some unstable, have been found for most elements.

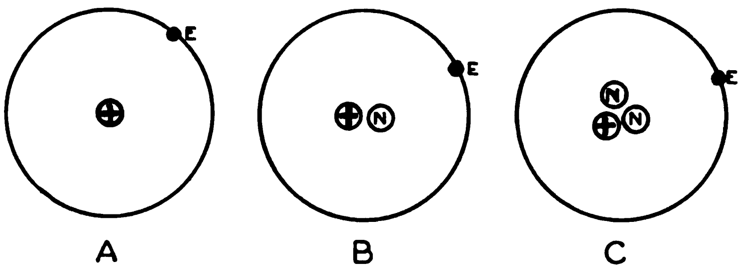

FIG. 1.—Diagrams representing three varieties of hydrogen atoms; the circle with the plus sign represents the proton which has a mass of 1 and a unit positive electrical charge; N, neutron which has the same mass as a proton but no electrical charge; E, electron having a mass $\frac{1}{1845}$ that of the proton or neutron and a single negative electrical charge. A, the common form of hydrogen. B and C, atoms of heavy hydrogen, B with 1 and C with 2 neutrons in the nuclei. B and C are called isotopes of hydrogen.

In their motion around the nuclei, planetary electrons are thought to be arranged in definite orbits, shells or energy levels. Outward from the nuclei these are designated by the letters K, L, M, N, O, etc. The maximum number of electrons that each orbit may contain is fixed. The K or innermost orbit is limited to 2 electrons. In this orbit in hydrogen atoms there is 1 electron; in helium there are 2 electrons. With progressively more complex atoms the L orbit begins to fill. It may contain as many as 8 electrons. In this orbit there would be 1 electron in lithium, and the capacity of the orbit would be reached in neon with an atomic number of 10 and 10 electrons (Figs. 1 and 2). The M orbit may contain 18 electrons, the N orbit 32, etc. The outer orbits are filled in the more complex atoms—those having the largest atomic numbers.

Atomic nuclei are stable structures; only those of the radioactive elements ever disintegrate spontaneously. Electrons are not so firmly fixed. In various ways they may be made to change their position within the atoms or they may even be completely removed

from the atoms. In a normal atom the electrons are all in their proper orbits. There may be one or more orbits outside these normal levels to which one or more electrons can be displaced. If this be done, the atom is in an excited state. Energy is required to move electrons in this manner, and if the electrons return to their normal levels energy is given off.

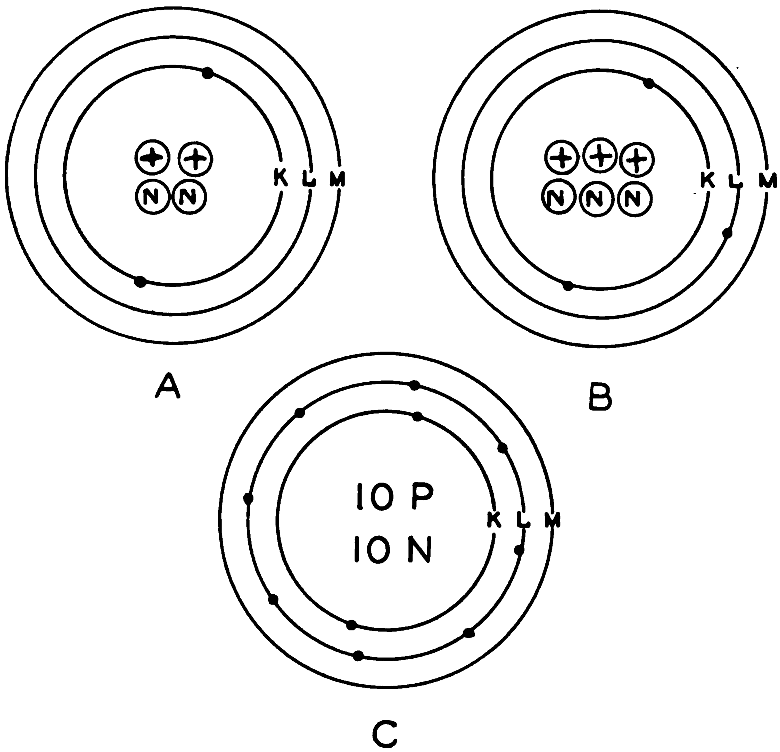

FIG. 2.—Two dimensional diagrams of some of the simpler atoms. A, helium atom with 2 protons and 2 neutrons in the nucleus and 2 electrons in the K orbit; B, lithium atom with 3 protons and 3 neutrons in the nucleus, 2 electrons in the K orbit and 1 in the L orbit; C, neon atom with 10 protons and 10 neutrons in the nucleus, 2 electrons in the K orbit and 8 in the L orbit.

If an electron be removed completely from the influence of the rest of the atom, then the atom has one unit of positive electrical charge in excess of its negative charge, it is said to be ionized, and a positive ion is produced. If an electron so separated attaches itself to a normal or neutral atom, then the negative charge will be greater than the positive charge and a negative ion is produced. A positive ion and an electron are called an ion pair.

An atom or a body is said to be neutral when the positive electrical charges of the nuclei exactly equal the negative charges of the

electrons. Electrons in excess of the normal number will impart a negative charge; electrons in less than the normal number will impart a positive charge. Similarly charged bodies will repel each other, while two bodies, one with a negative and the other with a positive charge, will attract each other. If they be connected by a conductor, electrons will flow from the negatively charged body to the conductor, and from the conductor to the positively charged body, until electrionic equilibrium is established. If, by chemical or mechanical means, as in a battery or generator, atoms can be dissociated so that a continuous supply of electrons is produced and sent through a suitable conductor, a current of electricity is the result.

In certain metallic substances like copper and aluminum, the electrons are not firmly attached to the nuclei. In such material, electric currents will flow readily, probably through motion of the surface electrons. These metals are called good conductors. In other substances the surface electrons are so firmly bound to the nuclei of the atoms that they are detached only with great difficulty. These, such as glass, hard rubber, and mica, are poor conductors, or insulators.

When positive and negative atomic portions are separated, there is an attraction between them and force is exerted which has a tendency to cause the electrons to reunite with the remainders of the atoms. This force, or pressure, by or upon the electrons, is spoken of as difference of potential, and is measured in arbitrary electrical units of electromotive force called volts. The quantity of electrons that flow through a conductor is measured in other units known as amperes, and the resistance of the conductor to the passage of the electrons in units known as ohms.

These units can be defined in terms of each other. Thus a volt is the amount of electromotive force or pressure that will cause an ampere of current to flow against a resistance of 1 ohm. An ampere is the amount of current that will flow against a resistance of 1 ohm with a pressure of 1 volt. An ohm is the amount of resistance that will require a pressure of 1 volt to cause a current flow of 1 ampere. The unit of quantity of electricity is the coulomb, which is 1 ampere maintained for one second. The unit of work is the watt, which is the amount of work that can be done with a current of 1 ampere and a pressure of 1 volt.

These units are too small or too large for measuring certain forms of electricity, so that others a thousand times greater or smaller are used. Thus a kilovolt is 1000 volts, a kilowatt is 1000 watts, and a milliampere is $\frac{1}{1000}$ of 1 ampere. The kilovolt and milliampere are units constantly used in *x*-ray work.

Because the abstract conception of units of electricity is frequently difficult for a student to grasp, an illustrative comparison often is made between electricity in a wire and water in a pipe. The pressure of the water is comparable to voltage, the amount of water flowing to amperage, and the size of the pipe or the opening in it, with the friction between the water and pipe, to the resistance or ohmage.

Thus a certain pressure is needed to cause water to flow through a pipe. Similarly pressure measured in volts is required for electricity to flow through a conductor. The amount of water that flows may be measured in cubic feet or gallons, while the flow of electricity is measured in amperes. The length and size of the pipe and particularly the opening in it, such as in a faucet, resist the flow of water. The resistance to the flow of electricity also is provided by the conductor and the appliances; it is measured in ohms. Obviously if there be no opening in the pipe, even though the water pressure be very high, the resistance will be so great that there will be no flow. Similarly resistance may be so high in an electric circuit that there may be no electron flow. Also if a water pipe has a large opening, the flow will be great and the pressure will fall. With little resistance in an electric circuit, the amperage will be high with a resulting drop in pressure (voltage).

In simple electric currents, as indicated above, there is a direct relationship between current, electromotive force, and resistance. This is expressed in Ohm's law in which current (amperes) is represented by I; Electromotive force (volts) is represented by E, and Resistance (ohms) is represented by R. As usually expressed in Ohm's law current equals electromotive force divided by resistance, or $I = \frac{E}{R}$ or amperes $= \frac{\text{volts}}{\text{ohms}}$. The formula may be transposed so that resistance equals electromotive force divided by current, or $R = \frac{E}{I}$, or ohms $= \frac{\text{volts}}{\text{amperes}}$; or the electromotive force is equal to the resistance times the current, or $E = RI$, or volts equals ohms times amperes.

DIRECT AND ALTERNATING CURRENT.

There are two kinds of electric currents, direct and alternating. In a direct current the electrons all flow in one direction. This direction is from the negative side of the battery or dynamo, through the wiring and appliances, back to the generator.

In an alternating current there are very rapid but periodic changes in the direction of the flow of the electrons through a conductor,

first in one direction and then in the opposite direction. Fig. 3 is a drawing of a curve used by physicists and engineers to illustrate an alternating current. In this figure the current represented by the part above the line is flowing in one direction, that below the line in the other. The arrows beneath show the direction of the current flow for each part of the curve.

In an alternating current the voltage is not constant as it is in a direct current. At A, Fig. 3, the voltage is zero. It increases to its maximum at B and then falls to zero again at C. At this point the direction of the current in the conductor changes; the voltage rises to its maximum at D and falls to zero at E. That part of an alternating current represented between points A and E is one cycle. A cycle, therefore, consists of a flow in one direction and then in the opposite direction back to the starting point. The curve in Fig. 3 represents $3\frac{1}{2}$ cycles. The number of cycles per second is also called the frequency of the electric current.

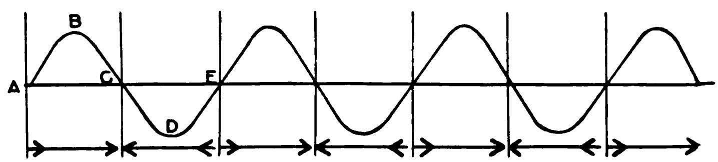

FIG. 3.—Curve used by physicists to illustrate alternating current. The arrows indicate the direction of electron flow.

The maximum voltage attained, as at B and D, is spoken of as the highest or peak voltage and is measured in peak volts. The average or effective voltage in an alternating current is spoken of as root-mean-square voltage. It is the square root of the average of the squares of the instantaneous voltage values for one-half cycle. Voltages in kilovolts are measured in average, effective, or root-mean-square kilovolts and in peak kilovolts. The peak voltage, whether in volts or kilovolts, is 1.41 times the root-mean-square voltage, or, conversely, the root-mean-square voltage is 0.71 times the peak voltage.

Although alternating currents of a greater or less number of cycles are generated, the common form is one of 60 cycles, which means that there are 60 cycles per second in this form of current. In a 60-cycle alternating current there will be 3600 cycles per minute. Inasmuch as each cycle consists of a flow of current in two directions, in one second there will be 120 changes in direction, or 7200 in one minute. Accompanying each half cycle, the peak voltage will be reached. This occurs so rapidly that, to all intents and purposes, the average or root-mean-square voltage is constantly maintained.

Alternating current is in more common use than direct current for lighting and industrial purposes. Direct current must be transmitted to the consumer at the voltage at which it leaves the generator. Because of this, a direct current of a considerable number of amperes must be transmitted over a large conductor and disposed of in the vicinity of the generating plant. By passing an alternating current through devices known as transformers the voltage and amperage can be changed. By so doing, an alternating current may be altered so that the voltage is very high and the amperage is low, the power or wattage remaining the same. In this form it may be sent for long distances over a relatively small conductor.

Alternating current usually is generated at from 2300 to 6600 volts. At this voltage it may be distributed throughout a community lying within a radius of 3 to 6 miles of the generating plant. This voltage is too high to send over wires into dwellings and business buildings. In the vicinity of buildings where it is to be used the current is passed through small transformers in which the voltage is reduced to 220 or 110 and the amperage is raised. These transformers usually are placed on poles in the street or alley close to the buildings that are supplied from them or in special transformer rooms in the buildings themselves.

By passing an alternating current through large transformers adjacent to a generating plant almost any voltage can be obtained. If the voltage be high enough, the resulting electricity may be sent over transmission lines for long distances. At the termination of the lines the voltage is reduced by other transformers to 2300 volts for distribution in a community, again being reduced by means of other transformers before it is used. Because alternating current can be distributed over large areas in this manner, large hydroelectric and other generating systems are made possible.

ELECTROMAGNETIC INDUCTION.

If iron filings be scattered over a piece of paper resting on the ends of a horseshoe magnet and the paper gently tapped, the filings will arrange themselves in a pattern like that illustrated in Fig. 4. If a wire carrying an electric current be passed through the center of the paper, the filings will arrange themselves in concentric circles around the wire. These patterns demonstrate the presence of a magnetic field around the ends of a magnet and surrounding a wire carrying an electric current, the lines formed by the iron filings illustrating the occurrence within the magnetic field of lines of force. A coil of insulated wire carrying an electric current is surrounded by

a magnetic field and is called a solenoid. If a bar of iron be passed through the center of the coil, the iron will become magnetized and an electromagnet be made.

If a wire forming a closed circuit be moved rapidly through or within a magnetic field in such a way that the wire passes through or cuts lines of force, an instantaneous electric current will be produced within the wire. Or if the circuit be stationary and the magnetic field be changed by starting and stopping the electric current, a similar indirect current will be created in the closed circuit. Electric currents produced in this way depend on electromagnetic induction for their origin and are called induced currents.

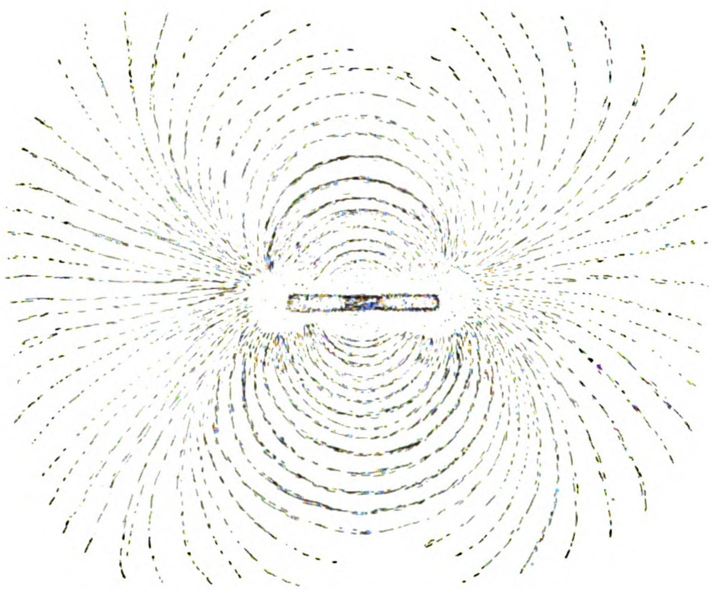

FIG. 4.—Pattern formed by iron filings on a paper held over the ends of a horseshoe magnet, demonstrating the presence of lines of force in the magnetic field of the magnet.

An induction coil is an instrument used in producing an induced current. It consists of an iron core around which are wrapped a relatively few turns of rather coarse wire, the ends of which are brought out of the coil and connected with a source of direct electricity. This coil of wire is known as the primary coil, and the circuit formed by it is called the primary circuit. Around the primary coil, but insulated from it, there is a secondary coil, consisting of a large number of turns of finer wire which makes a secondary circuit. When the primary circuit is closed or opened (spoken of as the make or break), a momentary current is induced in the secondary circuit

by the changing of the relationship between the lines of force in the magnetic field and the turns of wire in the secondary coil. If the primary circuit be rapidly opened and closed by an instrument called an interrupter, a current will be induced in the secondary circuit which is a high-voltage alternating current.

A transformer is constructed somewhat like an induction coil. One form, known as the closed core type, has a circular or rectangular core made of layers of transformer iron (Fig. 5), on one side of which is placed the primary coil and on the other the secondary coil. The two coils are carefully insulated from the core and from each other by the use of highly resistant materials and by placing the core and coils in a tank or container filled with dehydrated oil of high insulating quality. Perhaps a more efficient kind of transformer, known as the shell-core type (Fig. 12), has the primary coil around the core, the secondary coil around the primary, and extensions from the core around both coils like a shell.

A transformer is actuated by alternating current. The changes in the relationship of the lines of force in the magnetic field of the core, the primary coil, and the wires of the secondary coil necessary for an induced current are produced by the alternations or rapid changes in direction in the current through the primary circuit.

The voltage in the secondary circuit of a transformer depends on that of the primary circuit and on the relationship between the number of turns of wire in the primary compared to the number in the secondary coil. The ratio of the number of turns in the primary winding to the number of turns in the secondary winding is spoken of as the ratio of the transformer. For example, if there be 100 turns of wire in the secondary for each turn in the primary, a transformer is said to have a 1 to 100 ratio. Such a transformer will create an induced current in the secondary circuit which has a voltage approximately 100 times greater than that of the primary circuit, and because it increases or steps up the voltage, it is spoken of as a step-up transformer. Fig. 5 is a diagram of a 1 to 10 step-up transformer, the primary coil having 2 turns and the secondary 20 turns of wire. To illustrate its action, it may be assumed that with such a transformer for each volt of the primary current the secondary current will have 10 volts; if a current of 110 volts be sent through the primary of such a transformer, the secondary current will be one of 10×110 or 1100 volts.

The effect of a transformer on the amperage of the electric current is the opposite of that on the voltage. For each amperage value in the secondary coil and circuit, the amperage in the primary circuit is indicated by the ratio of the transformer. For example, in the transformer in Fig. 5, for each ampere consumed in the

secondary circuit there must be 10 amperes in the primary circuit. In a 1 to 100 ratio step-up transformer for each ampere in the secondary there must be 100 amperes in the primary circuit. Therefore, it may be said that a step-up transformer increases voltage and decreases amperage according to its ratio. Because of some resistance in the windings and some loss in the iron core, neither the voltage nor the amperage will have quite the values indicated by the ratio of the transformer.

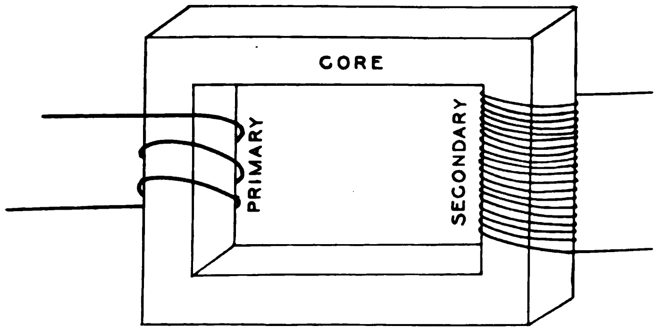

FIG. 5.—Diagram illustrating the construction and action of a transformer.

Not all transformers are step-up transformers. If the ratio of the number of turns in the primary and secondary coils be reversed so that the secondary has fewer turns than the primary, because the voltage will be stepped down or reduced, the transformer is called a step-down transformer. A step-down transformer will decrease voltage and increase amperage according to its ratio. In Fig. 5, if the two coils be reversed, the transformer will become a 10 to 1 ratio step-down transformer. In such a transformer, for each volt of primary current, approximately 0.1 volt of secondary current will be induced, and each ampere in the secondary will require 0.1 ampere in the primary circuit.

ELECTRIC CURRENTS OF A ROENTGEN-RAY MACHINE.

An x-ray machine uses three forms or kinds of electricity. One of these is the low-voltage high-amperage current received from the generating plant for use in the machine. This usually is alternating current of either 110 or 220 volts, the number of amperes varying from 10 to as many as 100 or more. When only direct current is available, a transformer type machine requires that this be changed to alternating by means of a rotary converter. The second kind of electricity has a very high voltage and a low amperage.

In equipments for roentgen diagnostic purposes this varies from 30,000 to 100,000 peak volts or from 30 to 100 peak kilovolts. The amperage varies from 1 to 100 or 1 to 500 milliamperes; from 0.001 to 0.1 or 0.001 to 0.50 ampere. Special equipments have been constructed to deliver higher milliamperes for very brief periods of time. The third kind of electricity has a maximum of 15 volts with an amperage that varies from 3 to 5½ or more amperes. This current has the special purpose of heating the filaments of the hot-cathode *x*-ray tubes and the filaments of rectifier tubes when such are used.

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CHAPTER II.

ROENTGEN-RAY MACHINES.

In early days x-rays were produced in gas tubes with electricity from static machines and induction coils. Induction coils used direct current electricity, requiring apparatus called interrupters in the primary circuits. The vacuum in the gas tubes was inconstant and difficult to regulate, and the interrupters were troublesome to keep in operation. When it was found that a high-tension transformer could be activated with alternating current and the resultant high-voltage current rectified and used in an x-ray tube, transformer-equipped machines rapidly replaced induction coils. A short time later hot-cathode x-ray tubes were invented. In these tubes the vacuum is constant and the voltage and amperage of the electric current can be controlled separately. Static machines have long been obsolete, and induction coils and gas tubes, in this country at least, have been so completely replaced that these older forms of equipment are now of little more than historic interest.

It would be impracticable to attempt to include a description of even a few of the large number of x-ray machines that are now in use and that are being built by different manufacturers. Although differing considerably in size, in outward appearance, in capacity and output, in the number, kind and arrangement of accessories, and in other particulars, all of them are much alike in their essential parts. The only material differences are in capacity and in the provisions for the rectification of a high-voltage current. Based on these differences x-ray machines can be grouped in three classes: (1) a larger form producing full-wave rectification of the high-voltage current by a special rectifier; (2) a medium-sized or smaller type, sometimes called a unit-type or self-rectifying apparatus, that depends on the x-ray tube for the rectification of its current; and (3) a class in which one or two valve tubes assist the x-ray tube in producing half-wave rectification of the high-voltage current. These three classes are quite similar in other respects. Because of this close similarity, the description of x-ray machines may be given in general terms applicable to any of them. For a detailed description of a particular model the manufacturer should be consulted.

The parts of an x-ray machine may be arranged in several ways. Formerly much of the apparatus was placed in a single cabinet with the switches, meters, etc., arranged in a control panel on one side or end. Except that the cabinet is low and mounted on wheels,

the mobile units still have the same arrangement with the switches, etc., on the top. In remote control models, which is the prevailing form, the apparatus is in two main parts. One of these parts is the control stand or panel mounted on wheels or fastened to the wall, containing the control apparatus. The other part contains the transformer, the rectifier, etc. The two parts are connected by insulated cables. This arrangement allows the transformer and the rectifier to be installed in a separate room, in a special built-in cabinet, or even on a shelf on the wall of the *x*-ray room. Except the stationary and mobile units, these machines require an overhead system for the high-voltage current. This is made of wires or tubing attached to the ceiling of the room.

The development of shock-proof cables and housings for the high-voltage leads and the *x*-ray tubes has made other arrangements possible. The overhead system has been eliminated. The transformer may be in one or two parts placed on the floor, mounted on a rail or track with the stand that carries the *x*-ray tube, or even used as a counterbalance for the fluoroscopic screen. The rectifier tubes may be oil-immersed and in the same container with the transformer. In the smallest machines the transformers and the tube may all be inclosed in a single compact shock-proof housing. To simplify the equipment and reduce its cost, all the apparatus may be grouped around a tilting table, and constructed so that a single tube may be used over the table for radiography and under the table for fluoroscopy.

For purposes of description the parts of an *x*-ray machine may be grouped under a few headings. One of these is the supply line and the current it carries; the others are the different electrical circuits of the machine itself. These are as follows: (1) the primary or low-voltage circuit including the primary coil of the high-tension transformer; (2) the secondary or high-voltage circuit including the secondary coil of the high-tension transformer; (3) the rectifier and the rectifier circuit when one is present, and (4) the filament circuit for heating the filament of the hot-cathode *x*-ray tube. All parts of the equipment function as a part of one or more of these four circuits.

SUPPLY-LINE CURRENT.

For the operation of an *x*-ray machine the best form of electric current is alternating of 60 cycles and 220 volts for larger machines and 110 volts for some of the smaller ones. Where other forms of alternating current must be used, especially constructed machines are necessary. Direct current must be changed to alternating by means of a rotary converter. This adds both to the size and cost

of the equipment. In inquiries concerning an x-ray machine, the kind of current and the voltage to be used should be specified.

Electric current for an x-ray machine should be as free as possible from fluctuations. Alternating current is distributed throughout a city or community at high potentials—usually at or above 2300 volts. By passing through step-down transformers, this is reduced to 220 or 110 volts in or near the buildings in which it is used. Different buildings containing various kinds of electrical apparatus may be connected to one of these transformers. If this be true, the demands on the transformer will vary from time to time, causing variations in the voltage supplied from it. Whenever possible, to eliminate this source of variable voltage, a machine should have a step-down transformer to which it only is connected.

The supply-line current is brought into the x-ray room at 110 or 220 volts over a 2- or 3-wire main line. If over a 2-wire main, the voltage may be either 110 or 220; if over a 3-wire main and the electric service is single phase, it usually is 110 and 220 volts. In a 3-wire main the middle wire is called the neutral wire. From it to either of the outside wires there will be 110 volts, while between the two outside wires there will be 220 volts. A 3-wire main, therefore, provides current of both 110 and 220 volts. These wires should end in a 2- or 3-pole, properly fused, safety switch. This may be called the supply-line switch (SLS, Fig. 8).

THE PRIMARY OR LOW-VOLTAGE CIRCUIT.

The primary or low-voltage circuit is so named because the primary coil of the high-tension transformer is included in it, and because it carries low-voltage electricity in contradistinction to the secondary or high-voltage circuit. It begins at the supply-line switch and includes the primary coil of the transformer. In this circuit are the devices for varying or controlling the primary voltage; a switch or contactor for closing the circuit, called the x-ray switch, magnetic switch, or magnetic contactor; and a voltmeter or other means or method of indicating or measuring the voltage in the circuit. Sometimes apparatus is included for altering the primary voltage to compensate for milliamperage changes. With some mechanically rectified equipment a polarity or pole-changing switch is included, and many machines include an overload relay circuit breaker.

A transformer can perform but one function. It can change, according to its ratio, the voltage and amperage of the alternating current that it receives. For commercial lighting and power purposes the voltage impressed on it is constant, so that the voltage

coming from it is also constant. If, as in an x-ray machine, it be necessary to vary the voltage from the transformer, the variation must take place in the primary circuit by changing the voltage going into the transformer. In other words, differences in output depend on differences in input. These variations are controlled by the operator with instruments for changing the primary voltage. Such instruments are of two kinds: autotransformers and rheostats.

A rheostat is made up of coils or sheets of metal having a high resistance which hinder or retard the flow of electric current passed through them. By means of a multiple-pole switch or control the amount of resistance can be changed, thus altering the amount of current permitted to pass through the primary circuit. Fig. 6 is a diagram of such an instrument having five coils of resistance wire. At a given amperage, if each coil will reduce the voltage 20 volts from a current of 220 volts, the primary current may be varied from 220 to 120 volts by moving the switch handle. For example, if the handle be on button A, none of the resistance coils will be in the circuit and the full 220 volts will pass. If the control handle be on button C, two of the coils will be in the circuit; each will cause a 20-volt reduction so that 180 volts will pass the rheostat. If the control handle be on button F, all of the rheostat will be in the circuit, the voltage will be reduced 100 volts, and 120 volts will pass.

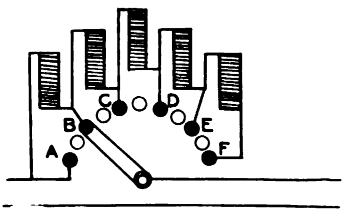

Fig. 6.—Diagram illustrating the construction and action of a rheostat.

An autotransformer performs the same function as a rheostat in the primary circuit of an x-ray machine but depends largely on magnetic induction for variations in the primary current. An autotransformer is constructed very much like any other step-up or step-down transformer. It consists essentially of a closed magnetic circuit in the form of a core made of thin sheets of iron of high magnetic quality. Instead of the primary and secondary coils of a conventional transformer, around this core is one continuous winding of heavy, insulated copper wire. This single winding is tapped at a number of predetermined points. To these taps are connected the lead-in wires from the supply line, and also the outgoing wires which usually are connected to the studs of suitable multiple-pole switches. The number of turns of wire between the taps to which the supply or feeder circuit is connected constitutes the primary section or primary winding of the autotransformer. The number of turns of wire between the taps to which the outgoing wires are connected, through the multiple-pole switches, constitutes

the secondary winding; thus the single wire around the core constitutes both the primary and secondary coils of the autotransformer.

When an electric current is passed through the primary winding of an autotransformer, there will be a current in each turn of wire, the voltage of which will be that fraction of the total impressed voltage that each turn is of the total number of turns of wire. In the secondary winding the voltage will be that of each turn of the primary winding, multiplied by the number of turns making up the secondary winding at the time being. By the use of multiple-pole switches provision is made for changing the secondary winding, with corresponding changes in the voltage of the current leaving the apparatus. A multiple-pole switch, sometimes called a line-voltage regulator, also may be installed in the primary to change the number of turns of wire in this winding. The ratio of transformation is always equal to the ratio of the number of turns between the feeder connection taps to the number of active turns between the outgoing taps.

Usually an autotransformer serves as a step-down transformer. By continuing the winding beyond one of the feeder or supply-line connection taps and connecting secondary taps to this continuation, an autotransformer can be made to serve as a step-up transformer. In this way, within limits, the primary voltage of an *x*-ray machine can be increased above that of the supply line.

An autotransformer is diagrammatically illustrated in Fig. 7. In the central part of the figure is the coil made up of a number of turns of heavy wire around a core of the shell type. Attached to the coil on the left are a number of inlet taps. The voltage of the supply line determines to which of these taps one of the wires is attached. From the lower part of the coil on the right are a number of leads from taps on the coil. These leads are connected to a multiple-pole switch that may be called the line-voltage regulator. The second supply-line lead is attached to this switch. Above the coil are two multiple-pole switches, the studs of which are attached to leads from the coil. These leads and switches are in the outlet or secondary side of the autotransformer, and wires from them lead to the primary coil of the *x*-ray transformer.

To simplify the explanation of the action of such an autotransformer, it is assumed that the supply line is connected through the inlet lead and the line-voltage switch in positions that will give 220 turns of wire in the primary winding; that the upper left-hand switch has studs and taps at intervals of 20 turns of wire, beginning at 60 and continuing to 200, and that the upper right-hand switch has much smaller intervals, there being 2 turns of wire in the inter-

vals between the studs on the switch, beginning at 0 and continuing to 18.

Under the conditions indicated in the preceding paragraph, if there be 220 volts impressed from the supply line, the voltage in each turn of wire would be $\frac{1}{220}$ of 220 or 1 volt. By using the left-hand multiple-pole switch, in which there are 20 turns of wire between the taps, voltage can be added or subtracted in steps of 20 volts or multiples of 20 volts from 60 to 200 volts. Similarly by

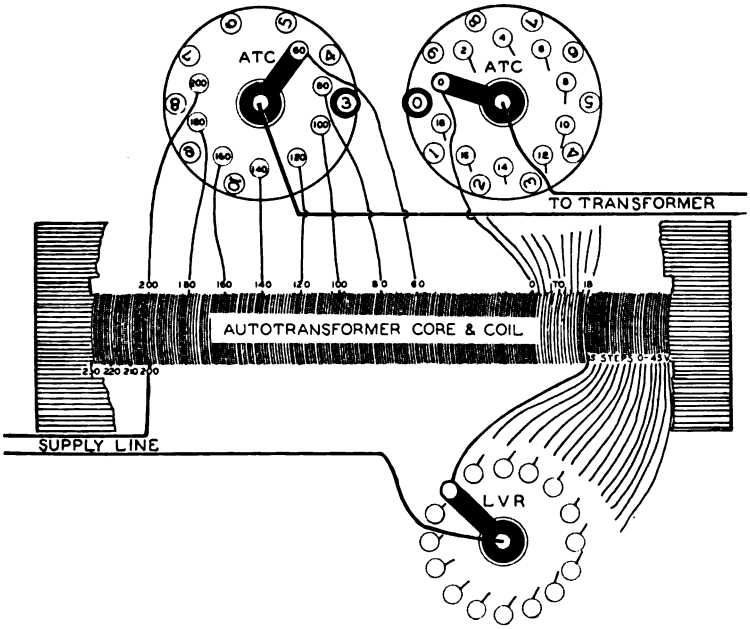

FIG. 7.—Diagram of an autotransformer. The core is of the shell type. One of the supply-line leads is connected to the line-voltage regulator, LVR, the other to an inlet tap on the coil. The line-voltage regulator has 16 studs on a multiple-pole switch. It functions to change the primary winding of the autotransformer. ATC, autotransformer controls, the one on the left has steps from 60 to 200 volts, the one on the right has steps from 0 to 18 volts. The outer rows of circles represent the illuminated dials on the autotransformer control switches. Further explanation given in the text.

using the right-hand switch, voltage can be added or subtracted in steps of 2 volts or multiples of 2 volts from 0 to 18 volts. By using the two switches together, the voltage taken from the autotransformer can be altered in steps of 2 from 60 to 200 volts. Provision is also made through the multiple inlet leads to compensate for variations in supply-line voltage, and through the line-voltage regulator switch to compensate for voltage changes caused by changes in milliamperage in the high-voltage circuit (see page 117).

If such an autotransformer be placed in the primary circuit of an

x-ray machine having an x-ray or step-up transformer with a ratio of 1 to 500, then for each 2 volts admitted to the primary coil of the transformer there will be 1000 volts or 1 kilovolt induced in the secondary coil: 60 volts will induce 30,000 volts or 30 kilovolts, 62 volts will induce 31 kilovolts, 64 volts will induce 32 kilovolts, etc. In this way the secondary or high-voltage current can be varied in steps of 1, from 30 to 109 kilovolts by the use of such an autotransformer.

Represented by the outer rows of circles in the upper part of the figure are dials fastened to the handles of the multiple-pole switches and moving with them. The numbers on these dials can be seen through holes in the top of the control panel where they are illuminated by a small electric lamp. These numbers indicate the high voltage produced by that autotransformer setting when the primary voltage is sent through the main transformer.

The autotransformer may serve in ways other than to control the primary voltage in an x-ray machine; from it may be obtained suitable voltages for other parts of the equipment. Electricity for the rectifier circuit, the filament circuits, the x-ray switch or magnetic contractor, a small electric lamp to illuminate the control panel, etc., may be obtained from the autotransformer.

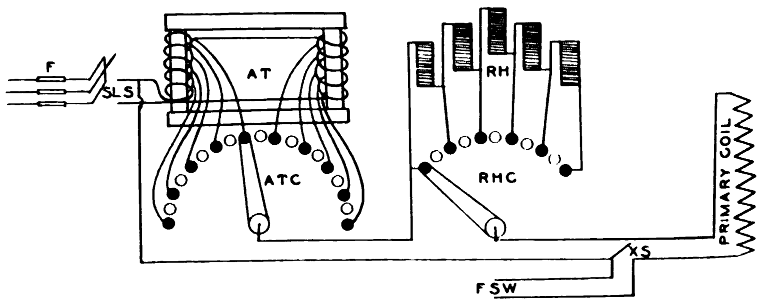

FIG. 8.—Primary circuit of an x-ray machine with combined autotransformer and rheostat control. F, fuses; SLS, supply line switch; AT, autotransformer; ATC autotransformer control; RH, rheostat; RHC, rheostat control; XS, x-ray switch; FSW, foot switch.

Machines that were made primarily for gas tubes have rheostat controls. Other models, made for hot-cathode tubes, depend primarily for voltage variations on autotransformers. All small and medium-sized x-ray machines of recent manufacture are equipped only with autotransformer control. Many machines still in use have both autotransformers and rheostats in the primary circuit (Fig. 8).

For use with a hot-cathode tube an autotransformer is much better than a rheostat. In a rheostat-controlled transformer,

changes in amperage in the secondary circuit will cause rather marked changes in secondary voltage, an increase in amperage causing the voltage to drop and a decrease in amperage causing the voltage to rise. In some machines with rheostat control, or when a combined control is used, these changes are often so sudden and so marked that it is difficult to control the secondary voltage. Similar changes take place with autotransformer control, but the effect of a change in amperage through the secondary circuit on the voltage is not nearly so marked as it is with rheostat control. Even with autotransformer control, a decided drop in secondary voltage will occur if a heavy secondary amperage be used.

Because of the difficulty of maintaining proper secondary voltage, a rheostat rarely is used for roentgenography but may be used in fluoroscopy and treatments.

The number of taps on the rheostat or on the autotransformer, each connected to a stud of a multiple-pole switch in the control panel, determines the number of voltage steps available for use in the primary circuit of the high-tension transformer. Since each voltage in the primary circuit when sent through the high-tension transformer will give a different value in the high-voltage circuit, the construction of the autotransformer also governs the available voltages in the high-voltage circuit. On many of the older machines still in use, the lowest primary voltage is 60 volts and the autotransformer is constructed so that the voltage may be increased in steps of 5 volts from this minimum to the maximum voltage. On these machines primary voltage steps of 5 volts give steps of approximately $3\frac{1}{2}$ peak kilovolts in the secondary circuit. Other older machines have differently constructed autotransformers.

Recently the greater speed of roentgenographic materials has made desirable smaller voltage intervals. For this reason equipments now being produced have autotransformers constructed with secondary voltage intervals of 1 or 2 peak kilovolts. This may be by means of two multiple-pole switches in the control panel each connected to taps from the autotransformer. One of these gives coarse steps—as much as 10 peak kilovolts between taps; the other gives much finer steps that may be added to the coarser steps on the first control. In this way voltage steps of 1 or 2 peak kilovolts may be obtained (Fig. 7).

All *x*-ray machines have a switch in the primary circuit called the *x*-ray switch which closes the circuit and admits the primary current into the transformer. The simplest form is a hand switch in one side of the primary circuit. When this is closed, the primary current flows from the control devices to the primary coil of the transformer, resulting in a high-voltage induced current in the

secondary circuit. A foot switch or automatic timer that bridges the x-ray switch may be added or may be located at a different place in the primary circuit. The wires of these devices carry the full primary current.

A much better x-ray switch is some form of magnetic switch, sometimes called a magnetic contactor or remote-control switch, controlled by a separate electric circuit (Fig. 9). By closing the circuit through the magnet, the switch is quickly closed, admitting the primary current to the high-tension transformer. Such switches or contactors usually are immersed in oil to prevent arcing during closing and opening of the contacts. With a switch of this sort the wiring of the primary circuit is always of the same length, the operator does not have a number of switches to open and close, and there

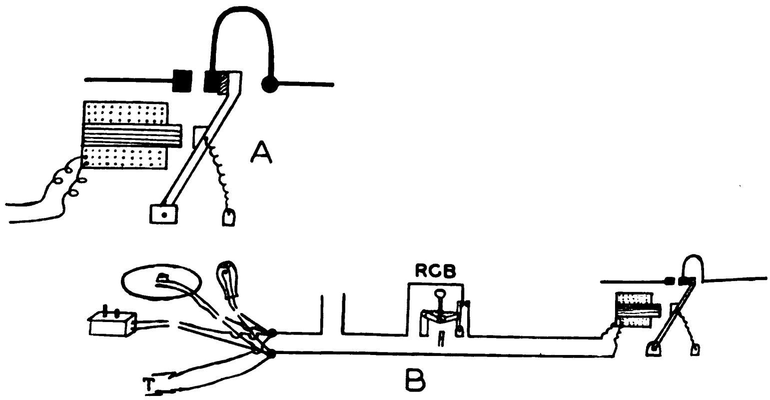

FIG. 9.—A, magnetic x-ray switch either in one or both sides of the primary circuit. B, circuit energizing a magnetic x-ray switch showing four ways in which the switch may be closed. The supply for the magnetic switch may come from the supply line or the autotransformer. T, automatic timer; RCB, relay circuit breaker.

may be a number of ways to control the circuit through the magnet. Among the latter may be mentioned a hand switch, a foot switch, an automatic timer, a push button for continuous operation as in treatment, and an attachment by means of which the circuit is closed and opened during the movement of the grid of a Potter-Bucky diaphragm.

A voltmeter and an overload circuit breaker may be included in the primary circuit. The primary voltmeter is connected across the primary wires between the control devices and the x-ray switch. It is called a prereading voltmeter because it registers the voltage of the current passing the controls which will be admitted to the transformer when the switch is closed. It is sometimes called a kilovoltmeter. On some machines these are calibrated in alternating current volts. Others are called potential indicators and

are calibrated in arbitrary scales reading from 1 to 100. Still others are calibrated in secondary voltages, either as average or peak kilovolts, indicating that the particular low-voltage primary current flowing through the instrument will produce approximately the indicated kilovolts in the secondary or high-voltage circuit (A, B, and C, Fig. 10).

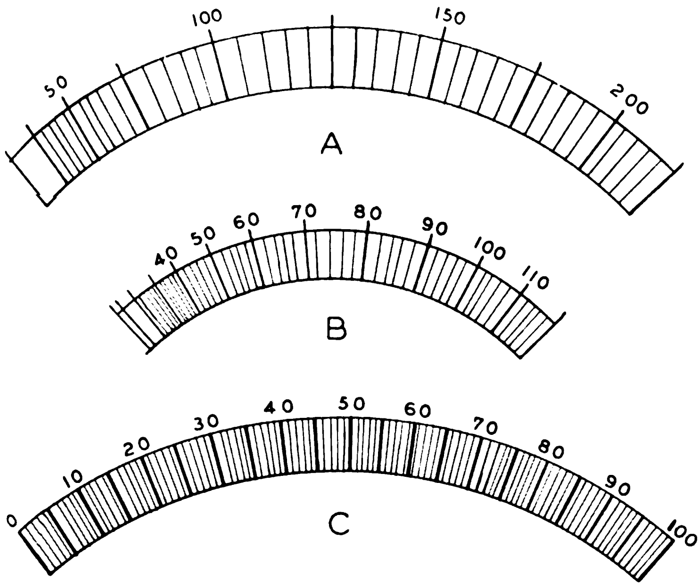

FIG. 10.—Scales of different types of voltmeters. A, scale reading in alternating current volts; B, scale reading in peak kilovolts; C, so-called potential indicator, the scale reading in arbitrary divisions.

Some x-ray machines are not equipped with voltmeters like those described. Instead, larger machines may have numbered dials attached to the multiple-pole switches of the autotransformer that are illuminated with a small electric lamp (Fig. 7). The numbers on these dials read in terms of peak kilovolts that will be produced in the high-voltage circuit when the primary voltage produced by that autotransformer setting is admitted to the x-ray transformer. Many of these machines have an additional multiple-pole switch and a small meter that is called a line-voltage meter. This additional switch is connected in the primary side of the autotransformer. It is used to add and subtract turns of wire from the autotransformer to adjust the primary voltage for different milliamperages that may be used. The line-voltage meter has a scale calibrated in arbitrary divisions to indicate the adjustments made by this additional switch.

Some smaller machines, those with a simple autotransformer and only a few voltage intervals in the primary circuit, may not have

a voltmeter, illuminated dials on the autotransformer switches, nor any other means of indicating the voltage in the primary circuit. On these machines dependence must be placed on the autotransformer settings as the sole indicator of primary and secondary voltage values.

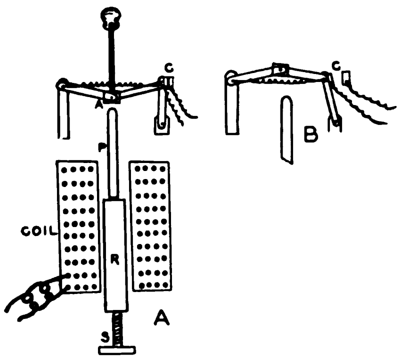

FIG. 11.—One form of overload relay circuit breaker. The coil is in the primary circuit. If an unusually heavy load be sent through the coil, the rod, R, is drawn into the coil, forcing the plunger, P, against A, pushing it past the center position, the spring opening the contact, C, breaking the circuit to the magnetic x-ray switch, and the switch opens. By means of the screw, S, the sensitiveness of the apparatus may be adjusted. A, contact closed; B, contact open.

An overload circuit breaker is a safety device sometimes installed in the primary circuit (Fig. 11). If there is an unusually heavy load, the circuit breaker automatically opens. Such a load may come from a spark-over in the secondary circuit to the apparatus or patient, or from an unintentionally large primary current. In case of accidental spark-over or unusually heavy current, the opening of the circuit breaker stops it, thus preventing serious injury to any person or the apparatus.

STEP-UP OR ROENTGEN-RAY TRANSFORMER.

The low-voltage high-amperage current of the supply line and the primary circuit is converted into the high-voltage low-amperage current of the secondary or x-ray circuit in the large step-up, high-tension, or x-ray transformer. This is much the most important unit of any x-ray installation. It is usually of the shell-core type. The core is made of soft iron in layers or sheets. The primary coil or low-voltage winding is placed directly around the core but insulated from it. It is made of a relatively few turns of heavy wire. For convenience of handling, the secondary or high-tension winding is frequently in the form of "pancake" coils placed around the primary coil and thoroughly insulated from it. These secondary

coils are made up of a large number of turns of fine wire. The core is continuous across the ends of the coils and down their sides (Fig. 12). The core and the coils are immersed in oil of high insulating quality inclosed in a rectangular box of metal or special nonconducting material. The purpose of the oil is to insulate the coils from each other and from the container and to assist in cooling the transformer.

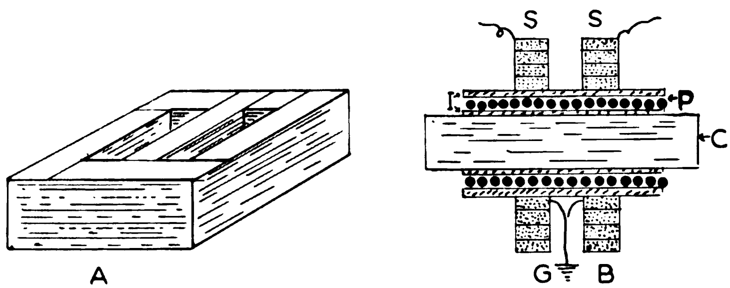

FIG. 12.—Shell-core type transformer. A, the core; B, the primary and secondary windings; C, core; P, primary winding of a few turns of heavy wire; S, secondary winding of a large number of turns of fine wire in pancake coils; G, ground.

The ratio of the number of turns in the primary winding of this transformer to the number of turns in the secondary winding, spoken of as the ratio of the transformer, is usually such that the maximum secondary voltage is delivered when the primary is connected directly across the supply line without the voltage being reduced by a rheostat or an autotransformer. For example, one that has a capacity of approximately 100 kilovolts and is made to operate on 200 volts of primary current will have a ratio of about 1 to 500. This means that for each turn of wire in the primary there will be 500 turns in the secondary coil; if there be 100 turns in the primary winding, there will be 50,000 turns in the secondary winding. In such a transformer, for each volt that is impressed on the primary, 500 volts will be induced in the secondary; and for each 0.002 ampere or 2 milliamperes used in the secondary winding, 1 ampere will pass through the primary. If 200 volts be sent through the primary coil, 100,000 volts or 100 kilovolts will be induced in the secondary.

The two heavy wires of the primary circuit usually enter the transformer through binding posts attached along one side of the case (P, Fig. 23). A resistance carbon may connect these two wires to protect the primary coil from surges. The resistance of this carbon is sufficiently high to prevent any undue loss of primary current; but high-voltage currents will pass through it, thus protecting the primary coil from damage. The terminals of the secondary coil of the transformer emerge near the ends of the transformer

case. To prevent the high-voltage current from jumping to adjacent parts of the apparatus, the wires are surrounded by insulating

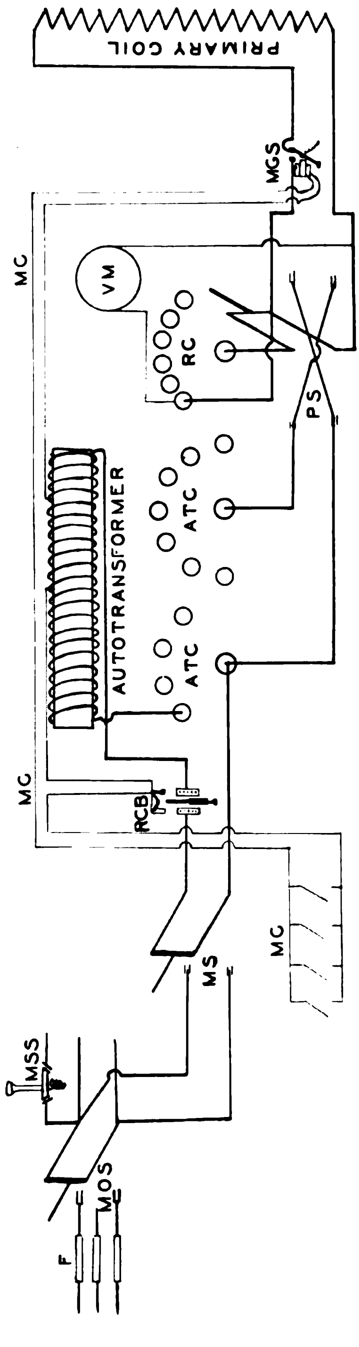

FIG. 13.—Wiring diagram of the primary circuit of an *x*-ray machine having a motor driven rectifier. MOS, motor switch; MSS, motor starting switch; MC, circuit of the magnetic switch; RCB, relay circuit breaker; ATC, autotransformer controls; RC, rheostat control; VM, voltmeter; PS, pole-changing switch; MGS, magnetic switch.

tubes of mica, bakelite, or similar material, or they are inclosed in shock-proof cables.

The current entering the transformer is alternating of a certain number of cycles. The high-voltage current leaving the transformer also is alternating of the same number of cycles. Each terminal is alternately negative and positive, once negative and once positive for each cycle. This change is spoken of as the change in the polarity of the transformer.

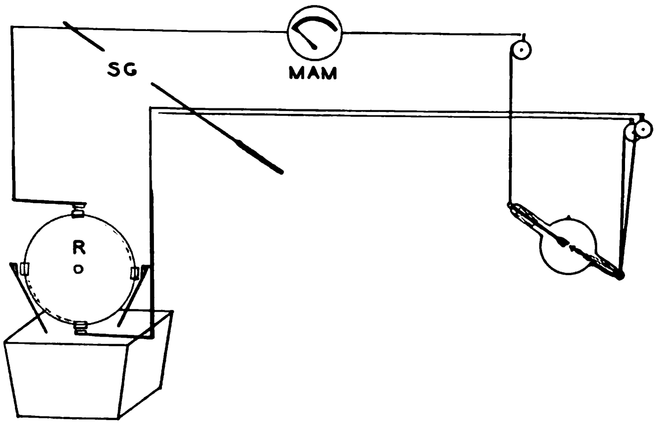

FIG. 14.—High-voltage circuit of an x-ray machine. The two wires to the cathode side of the tube also carry the filament supply. R, disk of the rectifier; SG, spark gap; MAM the milliamperemeter.

THE SECONDARY, HIGH-VOLTAGE, OR X-RAY CIRCUIT.

The secondary, high-voltage, or x-ray circuit includes the secondary coil of the high-tension transformer; it passes through the rectifier when one is present and ends in the x-ray tube (Fig. 14). In some installations this circuit is made of an overhead system of wires or tubes of substantial construction attached to the walls or ceiling of the room. From the overhead system the current is carried to the terminals of the tube by wires wound on spring reels to keep them taut. In other installations insulating cables reach from the overhead to the tube. The overhead system may be eliminated by directly connecting the transformer with the tube by means of such cables. When insulating cables are used, the tube also is insulated by immersion in oil in a special tube housing or by some similar means. The cables and tube inclosures are shock-proof. Such equipment removes the danger of accidental electric shocks from the tube or the wires leading to it.

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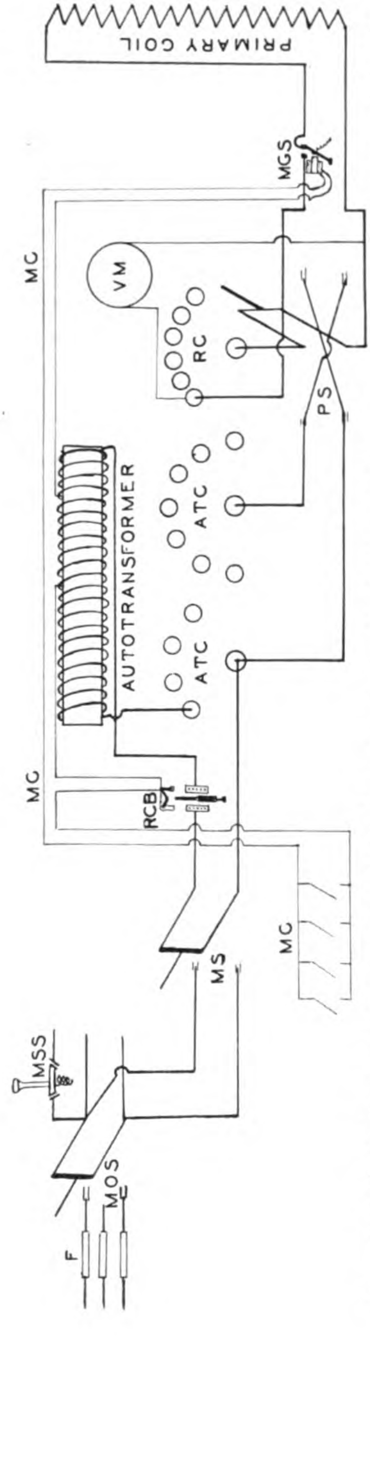

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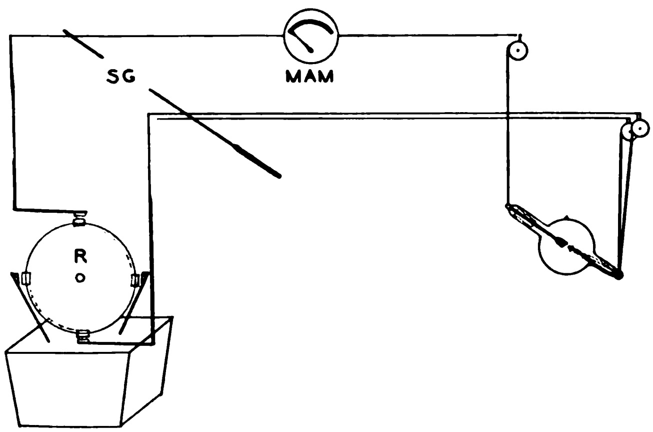

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Included as apparatus in the high-voltage or x-ray circuit are the x-ray tube, the milliamperemeter, sometimes a ballistic milliampere-second meter, and sometimes a spark gap. If installed in the high-voltage circuit the milliamperemeter is in the overhead system in series with the x-ray tube and in the anode side of the circuit. The ballistic milliampere-second meter may be similarly installed. Both of these meters may be connected to the neutral point of the secondary winding of the high-tension transformer and be installed in the control panel with the other control apparatus. This is the practice in self-rectifying apparatus and in all other machines that do not have an overhead system.

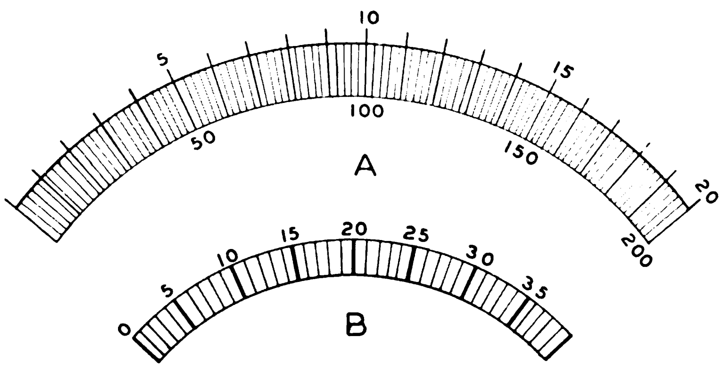

FIG. 15.—Scales of two types of milliamperemeters. A has a double scale, the bottom being ten times that of the top. The change from one to the other is made by a switch at the bottom of the instrument. B has a single scale.

The milliamperemeter or milliammeter is an instrument for measuring the milliamperes of the high-voltage current. In Fig. 15 are shown the scales of two such instruments illustrating the two types. A, in the figure, has a double scale, the top being 10 times that of the bottom scale. The change from one to the other is made by a switch at the bottom of the instrument or in the control panel. If this switch be closed in one direction, the reading is on the top scale; if in the other direction, the reading is on the bottom scale. In B there is a single scale reading from 0 to 40 milliamperes. In some equipments the milliammeter is not in the overhead or aerial system, but is mounted on the control panel. When so placed it is connected in the high-tension circuit at the neutral point of the transformer, the high potential between the instrument and the ground thus being eliminated.

The usual type of milliammeter has considerable inertia, requiring an appreciable time for the needle to come to rest and indicate the milliamperes flowing through the tube. It is not suitable for meas-

uring the milliamperage of very short exposures, many of which are made with currents high enough to damage the tube before such a measurement could be made. For this purpose a second current-measuring device, known as a ballistic milliammeter or ballistic milliampere-second meter, sometimes is installed.

A ballistic milliammeter has a scale reading from 0 to 50. One kind is installed in the high-voltage circuit. It has a horizontal scale with the indicator swinging from left to right. Another kind looks like an ordinary milliammeter. It has a needle that swings from left to right. It is attached to the neutral point of the high-voltage transformer and is installed in the control panel. The meter registers short exposures in milliampere-seconds (see p. 81). From the reading and the time, the milliamperage through the tube during the exposure can be determined. For example, a reading of 10 during a one-tenth-second exposure would indicate an amperage of 100; a reading of $12\frac{1}{2}$ during a one-twentieth-second exposure would indicate a 250-milliampere exposure, etc. For high-energy exposures with very short exposure times, a ballistic milliammeter is indispensable.

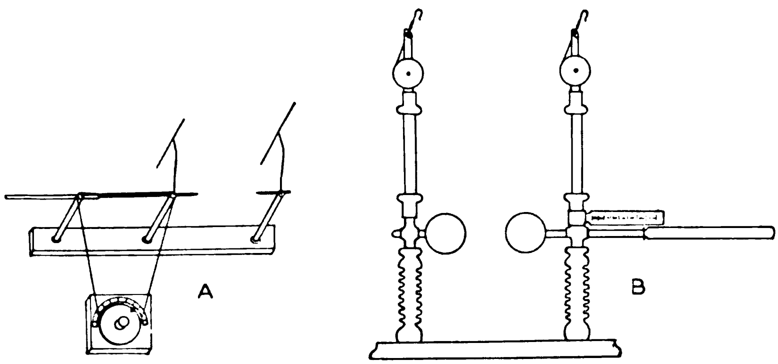

FIG. 16.—Types of spark gaps. A, a wall mounted point gap with the scale reading in inches. B, a portable sphere gap with the scale reading in peak kilovolts.

The spark gap in the high-voltage circuit is an instrument for measuring the voltage of the current to the *x*-ray tube (Fig. 16). At one time a spark gap was a part of every *x*-ray equipment; more recent installations do not include them. When present the spark gap is placed in parallel with the *x*-ray tube extending from one to the other of the high-voltage lines. The terminals of the gap may be in the form of blunt points or spheres.

The spark gap is mounted on insulated supports. One side is stationary, the other movable. In measuring the sparking distance of the high-voltage current, the tube is energized at the desired milliamperage and the movable side of the gap slowly is moved

toward the stationary side until the spark flames across the gap. When this occurs, the current is shut off and the distance jumped by the spark is measured or read from a scale provided for that purpose. The blunt point gap usually is read in inches. The scale of a sphere gap is calibrated to read in peak kilovolts.

ROENTGEN-RAY TUBES.

The earliest *x*-ray tubes were simple glass bulbs with fused-in electrodes. The cathode was in the end of the tube; the anode either in the other end or along one side. If such a tube be connected with an induction coil or other source of high-voltage electricity with air at atmospheric pressure within the tube and with the electrodes far enough apart that there will be no spark between them, then, while the current is applied, if the pressure in the tube be reduced by a vacuum pump, a very interesting and unusual series of phenomena will occur within the tube. As the air is removed and the pressure is decreased, a stage is reached in which the current passes through the tube. This is indicated by an illumination within the tube extending between the terminals. As more of the air is removed while the current is flowing, the luminosity within the tube undergoes a series of changes both in color and arrangement. Finally, when the vacuum becomes sufficiently high, the tube becomes completely dark and the current will no longer pass.

At one point in the evacuation of the tube a faint beam of light may be seen emerging at right angles to the cathode terminal of the tube. This beam of light is propagated in a straight line until it strikes the glass wall of the tube or the other electrode. At the place of impact against the glass there will be a faint fluorescent glow. This stream of light in a vacuum tube is called the cathode stream, and it is said to be made up of cathode rays. When cathode rays strike the glass wall of the tube, *x*-rays are produced. A tube of this sort was in use by Professor Roentgen at the time of the discovery of *x*-rays. Experimentation has proved that the cathode stream is made up of electrons and that the cathode rays are electrons traveling in a vacuum. At the present time the terms **cathode rays** and **cathode stream** are reserved to designate electrons traversing a vacuum tube.

All of the earlier *x*-ray tubes were gas tubes. The air was partially exhausted from the bulb and the arms, either with or without replacement by hydrogen or other gases. The tubes depended for their current-carrying capacity on the electrons liberated by the ionization of the gases they contained. Electrons or cathode rays passed from the cathode of the tube and positive ions in the opposite

direction. All such tubes possessed one undesirable feature—the inconstancy of the vacuum within them, the vacuum determining both the voltage and milliamperage the tubes would carry. To overcome this difficulty, the hot-cathode or electron tube was invented by Dr. W. D. Coolidge.

Previous to the invention of the Coolidge tube, it had been shown that metals heated to incandescence would give off electrons even in highly evacuated spaces, and that the better the vacuum the more efficient the electron emission. This phenomenon is known as the thermionic emission of electrons. Coolidge made use of this fact by making the cathode of an *x*-ray tube of a spiral of tungsten wire that could be heated by an electrical supply separate from the high-voltage current applied to the tube. All the gases were evacuated from the tube. In a tube of this sort the milliamperage and voltage controls are independent of each other, and either can be changed within limits without affecting the other.

Unlike a valve tube, a hot-cathode or electron *x*-ray tube operates at saturation. Through regulation of the amperage of the current heating it, if the temperature of the filament of a tube be set at a predetermined point and then high voltage be applied to the tube beginning at low and continuing to higher voltages, in the beginning the milliamperage of the high-voltage current will rise as the voltage is increased. However, a point is soon reached when the milliamperage through the tube becomes stationary, and further voltage increases will have little effect on it. When an increase in voltage will not raise the milliamperage, the tube is operating at saturation. This means that all the electrons emitted by that particular filament temperature are utilized in carrying the high-voltage current through the tube. All hot-cathode *x*-ray tubes are constructed to operate at saturation (see p. 50). By changing the filament temperature the milliamperage can be altered without seriously affecting the voltage; conversely the voltage can be increased or decreased without much effect on the milliamperage.

In a hot-cathode *x*-ray tube the electron stream is focused in such a way that it strikes a limited area of the anode face or target. The focusing device is around and behind the cathode filament. The surface of the anode to which the electrons are directed and against which they strike is known as the focal spot or focal area of the tube.

The earliest Coolidge tube was known as the universal type, to which later was added the radiator type. The universal Coolidge tube (Fig. 17) consisted of a spherical glass bulb about 7 inches in diameter with two hollow glass arms projecting from opposite sides. Fused into the end of the larger arm was an attachment which sup-

ported a molybdenum rod. To the end of this rod was welded a large piece of metallic tungsten which formed the anode or target. In the smaller end of the tube there was a small, flat, circular coil of tungsten wire, the filament, which formed the cathode of the tube. The terminals of the filament were brought out through the glass and fastened to an electrical connection at the end of the arm. The filament was surrounded by a small cylinder of molybdenum which acted as the focusing device, directing the electron stream to the focal spot of the anode.

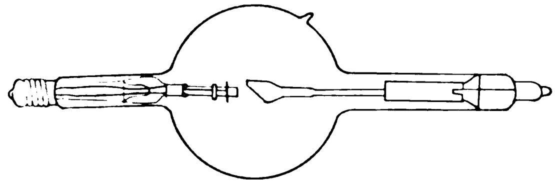

FIG. 17.—Universal type Coolidge tube.

Universal Coolidge tubes were designed to operate only on rectified current. When in use, the anode of the tube could be heated to incandescence. The heat was dissipated by radiation through the glass wall of the tube. Based on the size of the focal spot, three forms of universal Coolidge tubes were made. These were known as the fine, the medium, and the broad focus tubes.

The fine focus tubes were designed chiefly for fluoroscopy and fine roentgenographic work, the medium focus tubes for heavy roentgenography and superficial treatments, and the broad focus tubes for heavy flash exposures and treatments at moderately high voltages. Because of changes in hot-cathode tube design, universal Coolidge tubes now are used infrequently for radiography. Many of them are still in use, however, for roentgen therapy.

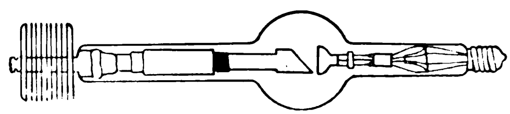

FIG. 18.—Radiator type Coolidge tube.

The original radiator type Coolidge tube (Fig. 18) had a glass bulb about $3\frac{3}{4}$ inches in diameter. The focusing device around the filament was a hemispherical shell. The anode or target was a small tungsten button cast into the end of a solid copper rod and set in the face of the anode in a plane at an angle of 45 degrees with its long axis. The copper rod was carried out through the glass of the anode arm and had attached to it a number of copper disks which made up the radiator. The heat from the anode was con-

ducted by the copper rod to the radiator which cooled in the air. Two types of these tubes were made, one with a maximum permissible amperage of 10, the other of 30 milliamperes.

The radiator type tubes brought about one revolutionary change in tube construction and usage. As long as these tubes were operated within their rated capacity, they could be attached directly to the terminal of a transformer without rectification of the current. Their introduction made possible the unit-type, or self-rectifying, *x*-ray machine. (See Chapter III.)

In recent years many changes have been made in the construction of hot-cathode *x*-ray tubes and several manufacturing concerns have produced tubes of different designs. The chief changes have been (1) in the design of the anode and filament to permit of much higher energy ratings with smaller effective focal spot sizes, (2) in the provisions made for dissipation of the heat from the anode, (3) in reducing radiation from the stem of the anode, (4) in building into the tube provisions for limiting the *x*-rays to the beam from the focal spot, (5) in shock-proofing the *x*-ray tube and the wires leading to it, and (6) in building a tube with a rotating anode giving a much higher capacity with the smallest possible focal spot.

The universal and radiator type Coolidge tubes have the anode face at an angle of 45 degrees with the axis of the anode stem and have an elliptical focal spot. In hot-cathode tubes of recent manufacture these have been changed to an anode with an inclination of 19 or 20 degrees, with a so-called line, band, or Benson focus. A focus of this sort is rectangular in shape, vertically placed on the anode face. This type of focus is made possible by the use of an elongated spiral filament instead of a flat, circular coil. This arrangement of filament and anode gives a relatively large area in the actual size of the focal spot, while the projection of the focal spot in the direction of the emerging rays is approximately one-third as large (Fig. 19). Considerably greater energies may be applied to anodes of this type with much smaller projected focal spots than was possible with older types.

Except in some forms of therapy tubes, heat dissipation and cooling by radiation to the air around the tube is no longer used. Cooling is now done by radiators attached to the anodes, by water reservoirs on the anodes, and by immersion in oil. Of these the more common are the tubes cooled by radiators and those cooled by immersion in oil. The anode stems of radiator tubes are still made of copper, but they are more massive with greater heat storing and carrying capacity. Water-cooled tubes have a hollow anode stem with a water reservoir attached to it, the water reaching nearly to the back of the button on the face of the anode. The heat is carried

away from the anode by a thermosyphon arrangement circulating the water in the stem and the reservoir. Tubes of this sort must be operated with the reservoir at the same or higher level than the anode.

Cooling of x-ray tubes by immersion in oil was introduced by Coolidge in 1920. The first application was in self-rectifying equipment for dental roentgenography. The tubes were small and had a limited capacity. They were inclosed in the same housing with the transformer and other high-tension apparatus. More recently these tubes have been made larger and adapted to equipments providing rectified current in both roentgenographic and therapy apparatus. They are inclosed in a ray-proof and shock-proof housing filled with oil. Heat reaches the oil by radiation or by means of a radiator attached to the anode and bathed in oil. A part of the housing of

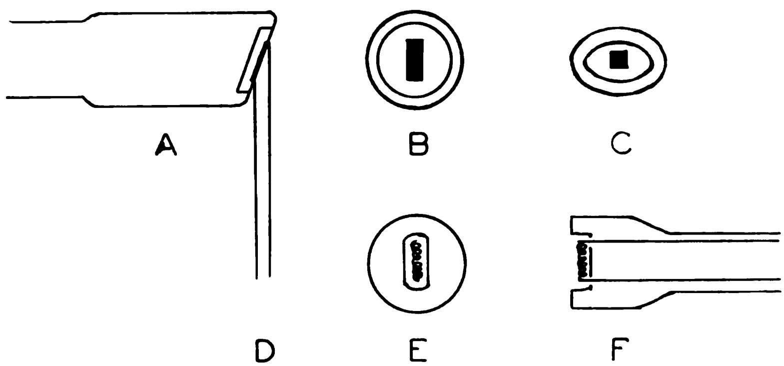

FIG. 19.—Line, band, or Benson focus x-ray tube. A, the anode seen in profile with the focal spot projected toward D; B, the actual size of the focal spot; C, the effective or projected focal spot; E, the filament; F, the construction of the cathode.

these tubes is a special chamber to allow for expansion and contraction of the oil on heating and cooling. Cooling may be aided by provision for circulating the oil, by circulating water around the oil, and by a small electric fan as a part of the tube housing. Tubes for immersion in oil may be much smaller than air-cooled tubes, thus permitting shock-proof installations of such size that the flexibility of the other forms is preserved.

The rotating-anode tube is the latest development in x-ray-tube design (Fig. 20). The tube is made of heavy, heat-resisting glass with projecting anode and cathode arms. The anode is made of a solid disk of tungsten, or of a heavy copper cylinder with a conical tungsten facing. A shaft attached to the anode extends into the anode arm of the tube and has on it the rotor of an induction type alternating current motor. Suitable bearings permit of rapid rota-

tion of the anode. The face of the anode is beveled near the margin, giving an angle of 15 or 20 degrees, or the tube may be mounted in the housing at such an angle that the anode face forms an angle of 15 degrees with the long axis of the housing. On the outside of the anode arm is the stator winding of the motor. The anode rotates at or about a speed of 3000 revolutions per minute.

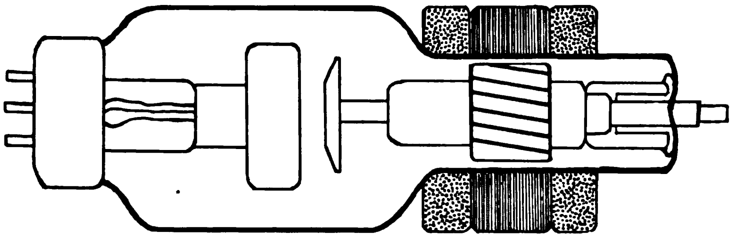

FIG. 20.—Rotating-anode *x*-ray tube. The rotor of the motor is inside the anode arm, the stator around it. The anode is a beveled tungsten disk. There are 2 filaments and 2 focal spots, 1 and 2 millimeters square.

The cathode arm of the tube contains the filament attachment and support, with a single or a double filament. The single or double filaments are eccentrically placed near the bottom of the tube and are located so that the electron stream from the filament strikes near the periphery of the anode.

The filaments are constructed to give a line, band, or Benson focus to the tube. The effective focal spots are very small, the double-focus tube having effective focal spots that are 1 millimeter and 2 millimeters square.

The entire tube is placed in a shock-proof and ray-proof housing and may be immersed in oil. Shock-proof cables carry the high voltage current to the tube and there is a separate electrical connection for the motor. Rotating-anode tubes are suitable only for fully rectified current.

Exposures are made with a rotating-anode tube only while the anode is rotating. In this way the metal heated by the impact of the electron stream is replaced by the cooler metal of the anode face. While the spot from which the *x*-rays originate is small, the amount of anode surface from which the rays originate extends entirely around the anode and is comparatively quite large. The tube therefore has the smallest effective focal spot giving maximum definition and detail. At the same time high-energy, short-time exposures are possible. This reduces unsharpness on the films from voluntary and involuntary motion to a minimum.

An *x*-ray tube having two filaments and a small and a large focal spot is a very satisfactory form for general use (Fig. 21). The small

spot is used in long, low milliamperage exposures to secure good detail and definition on the films. The large spot is used in short, high current exposures to eliminate deleterious effects from involuntary motion of parts of the body being examined. Usually the size of the large spot, both actual and projected, is about three times that of the small spot. To prevent accidental overloading of the small focal area, an electric light or other form of resistance is placed in the circuit of the small filament.

Coolidge and Moore showed that radiation from the face of the anode outside the focal spot in the universal type Coolidge tube was one-ninth that from the spot itself, and that considerable radiation was emitted from the body and stem of the anode. Radiation from these sources was not only undesirable from a roentgenographic standpoint, but, if scattered about the x-ray room, had in it some elements of danger to the operators themselves. Stem radiation has been eliminated by the use of copper anode stems and by the provisions made for ray-proofing the tube itself.

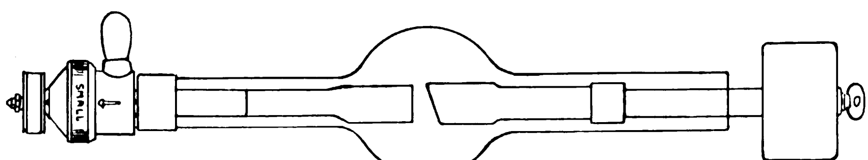

FIG. 21.—A double focal spot, band focus x-ray tube. This tube has two filaments and two focal areas on the anode. A switch at the cathode terminal changes the current from one filament to the other. To prevent overloading, a small light globe is in the circuit of the small filament.

Formerly it was the practice to use x-ray tubes in open lead-glass bowls. This prevented projection of rays in a lateral direction from the tube but not through its open top. Later two-part lead-glass shields were made that completely inclosed the tubes. Ray-proofing has been further advanced by making portions of the tube of lead and other metals relatively opaque to Roentgen-rays, one form having the entire outer envelope made of metal, another being made to fit inside a metallic protective cover. Lead glass also has been used for the body of the tube with a small window of lime glass for the emerging rays.

The possibility of the operator of an x-ray machine or a patient accidentally getting a high-tension electric shock from an x-ray tube or the leads running to it has been an ever present danger in every x-ray laboratory. The danger from shock has been eliminated by shock-proofing. This has taken two forms. In one, the x-ray tube and all the high-tension apparatus are immersed in oil in a

single grounded housing. Of necessity such an equipment must be of the unit type, thus of small size and of a limited capacity. In the second form the tube is inclosed in a grounded metal container with highly insulated flexible conductors leading from the aerial system or from the transformer directly to the tube.

X-ray tubes are rated according to the size of the effective or projected focal spot and the provision made for cooling the anode. The focal-spot size usually is given in millimeters square. A rating chart is provided with each tube. From this may be obtained the energies in terms of milliamperage and peak kilovolts that may be used with safety with that particular tube. The maximum energy that may be used is largely a question of the size of the focal spot and the provisions for cooling. In short high-energy exposures the melting point of tungsten at 3300° C. is the danger point. It has been said that the safe energy tolerance of the focal spot is 200 watts (milliamperes times volts) for each square millimeter of actual focal spot size, based on a one-second exposure. For continued exposures, as in fluoroscopy, the rating is based on the ability of the cooling mechanism to absorb and conduct the heat away from the tungsten anode.

It is possible with any *x*-ray machine to make an accurate determination of the size of the focal spot, or spots, of any *x*-ray tube. This is done by making a pin-hole exposure of the focal spot. Drill a shallow depression in each side of a piece of sheet lead. The depressions should be opposite each other and should not go entirely through the lead. With a small sharp point, like that of a needle, complete the hole. When finished it should not be more than .5 millimeter in diameter. Place this hole in a vertical line exactly beneath the focal spot of the tube and exactly half way, say 12 inches from tube to lead and 12 inches from lead to film, from the focal spot to a non-screen film in a cardboard holder. Make an exposure of 50 milliampere-seconds at 70 peak kilovolts or the equivalent. More than one exposure can be made on the same film using slightly different exposure factors. Process the film. The focal spot will be projected in its exact size plus the size of the diameter of the hole in the lead.

The distribution of the radiation emitted from the focal area of the tube may be studied by making similar exposures, but with the lead plate twice the distance from the film as it is from the tube anode. The image of the focal area will be enlarged and the distribution of *x*-rays emitted may be determined by the degree of darkening of the image in its various parts.

The rating charts also show the permissible energies for the different types of current supplied by the high-voltage generating appa-

ratus. This is greatest for full-wave rectified current from mechanical or valve-tube rectifiers, less for half-wave rectified current from single valve-tube rectifiers, and least when the tube must rectify its own current.

THE RECTIFIER AND THE RECTIFIER CIRCUIT.

The electricity from the high-voltage transformer of an x-ray machine is alternating in type. By including special equipment as a part of an x-ray machine, it is possible, without loss in voltage or milliamperage, to change this to current flowing in one direction. The current is interrupted and pulsating, but it is unidirectional, and it is called rectified current (Fig. 24). X-ray tubes can be used without rectification, but most of them function more efficiently on rectified current; current flowing from the negative terminal of the transformer to the cathode side of the tube, and from the anode side of the tube to the positive terminal of the transformer. Rectifying mechanisms are of two types: (1) mechanical rectifiers, and (2) valve-tube rectifiers.

MECHANICAL RECTIFICATION.

A mechanical rectifier is a rotating commutator or rotating circuit changer consisting of a synchronous motor with one or two disks or a set of cross-arms attached to its shaft (Figs. 23 and 26). As will be seen later, the motor must revolve the disk or cross-arms at a definite speed. With 60-cycle alternating current this rate must be 1 revolution for each 2 cycles or 1800 revolutions a minute. For alternating current of a different number of cycles there must be other designs operating at other speeds. Such a motor is said to revolve in synchronism with the generator supplying the electric current and is called a synchronous motor.

Because synchronous motors have a very low starting torque, they are provided with a special starting winding to bring them up to synchronizing speed. In starting, the current first is sent through this winding until approximately the speed of 1800 revolutions a minute is reached; this winding is then either manually or automatically disconnected, the current being sent through the running winding. The starting winding usually draws a rather heavy amperage and is not designed to remain in the circuit after the motor has attained the proper speed.

Because of this such motors have a special starting switch or connection. This may be a double-throw switch that is closed one way for starting and then the other for running. There may be a switch that is closed to the left by hand and when released is thrown

to the right or running side by a spring. There may be a push button and a knife switch, the button being closed until the running speed is reached. On the shaft of the motor there may be a centrifugal switch that is thrown out of contact when the motor has reached a certain speed. If the motor is designed with a manually operated cut-out switch, great care must be exercised in opening it after the motor has attained the proper speed. A failure to observe this precaution probably will cause the winding to burn out.

The presence of the synchronous motor as a part of an x-ray machine requires a separate electric circuit for its operation. The current supply is taken from the supply line or autotransformer and may be either of 110 or 220 volts. The motor switch is mounted on the control panel. This circuit is diagrammatically represented in Fig. 22.

The disk in a disk rectifier is made of mica, bakelite, or some other nonconducting material. On its edge, separated by 90

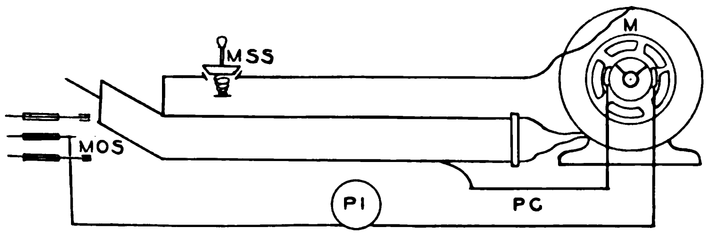

FIG. 22.—Motor circuit of an x-ray machine including the polarity circuit. The motor-starting switch, MSS, must be closed at the same time as the motor switch, MOS. PI, polarity indicator; PC, polarity circuit; M, motor.

degrees, there are four metallic sectors. These are connected in pairs by wires weaving back and forth through the edge of the disk or by a metal bar along the edge of the disk. As shown in Fig. 23, A is connected to B, and C to D. When the disk is turning, these sectors revolve on the inside of four collectors arranged in two pairs. Those of one of these pairs, separated by 180 degrees, are connected to the terminals of the secondary coil of the transformer (E and F), and those of the other pair to the tube circuit, X to the cathode side of the tube and Y to the anode side.

To understand the action of the disk rectifier, reference is made to Fig. 23, A and B. When the disk is in the position shown in A. the high-voltage current emerging from the negative side of the transformer will be at its maximum value or at the peak of the wave. It will flow through the collector to sector A, through the wire in the edge of the disk to B, from B to X, and then over the high-voltage circuit to the cathode of the tube. After passing through the tube,

it will pass back over the other side of the circuit through D and C into the transformer.

During the next half cycle of the alternating current the polarity of the transformer will change, and the disk, revolving once for each two cycles, will make a fourth of a revolution and come to the position illustrated in B. In this position the current will pass from the negative terminal of the transformer through B and A to the cathode side of the tube, and back through C and D to the positive

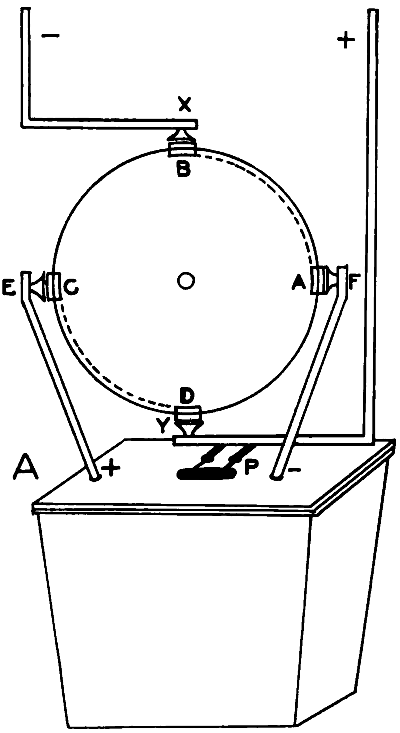

FIG. 23.—Illustrating the action of a disk-type rectifier. The explanation is given in the text.

side of the transformer. By the time the polarity of the transformer has changed again, the disk will be in the position indicated in A, and the process will be repeated.

From this explanation it becomes clear that the speed of the disk must have a definite relationship to the alternations in the current. As stated before, with 60-cycle current, this is 1 revolution for each 2 cycles or 1800 revolutions a minute. If for any reason there should be a variation in the cycles of the current, the motor changes its speed to correspond, so that it always travels at a rate

of 1 revolution for each 2 cycles. The disk of the rectifier must have a definite position on the shaft of the motor, which must be such that the sectors come opposite the collectors when the current is at the peak of the voltage.

If Fig. 23 is now examined again, it will be seen that when the disk is in the position halfway between that represented in the two figures the sectors will be halfway between the collectors and no current will flow. This produces interruptions in the rectified current, making two pulsations for each cycle, one for each half cycle. It will be seen further that only the peaks of the high-voltage current will be rectified. While that portion of the current is passing which is of lower voltage, the sectors on the disk will be in the halfway position between the collectors, and no current will be flowing. This unidirectional, high-voltage, pulsating current is diagrammatically represented in Fig. 24, which should be compared with Fig. 3.

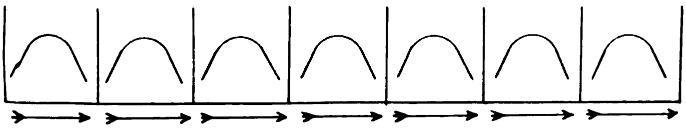

FIG. 24.—Rectified current, the arrows indicating the direction of electron flow. Compare with Fig. 3.

From a further consideration of Fig. 23, it may be seen that when the disk is in the position illustrated the terminals of the transformer may be of the polarity indicated or just the opposite. In A, if the left terminal should be negative, the current would attempt to pass through C and D and through the tube from the anode side, which is impossible. If this occurs, the motor is said to be off polarity. To determine the polarity of the motor with reference to the transformer, an instrument known as a polarity indicator is provided.

The polarity indicator is a direct current voltmeter in a branch circuit in which there is a rectifying commutator on the motor shaft (Fig. 25). The commutator suppresses that part of the alternating current flowing either in one direction or the other, thus causing the needle of the indicator to move either to the right or to the left. This enables the operator to determine whether the motor is in correct polarity with reference to that of the transformer. The supply for the polarity circuit may come from the supply line, the motor circuit, or the autotransformer.

If the polarity be wrong, it may be changed by opening and closing the motor starting-switch until the motor catches step in correct

polarity, usually when the needle of the indicator swings to the right. Another method of obtaining the correct polarity is by means of a reversing or pole-changing switch (PS, Fig. 13). By means of such a switch the polarity of the transformer is changed by changing the direction of the primary current into it. If a switch of this sort be in use, it is closed either to the right or left, depending on the deflection of the indicator needle.

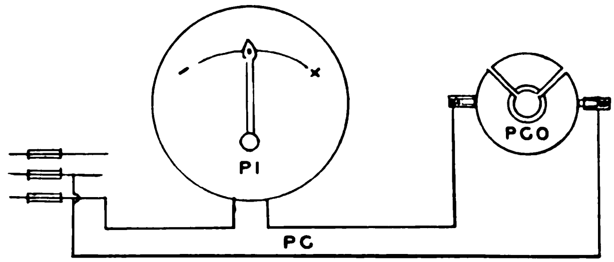

Fig. 25.—Polarity circuit. PI, polarity indicator; PCO, polarity commutator mounted on the end of the motor shaft.

DOUBLE-DISK RECTIFICATION.

Two disks, one mounted on each end of the motor shaft, have been used for rectification of the high-voltage current from a specially constructed double high-tension transformer. In an apparatus of this kind each transformer produces one-half the voltage which is rectified by one of the disks. This apparatus has the advantage of being able to utilize smaller disks. The peripheral speed of these smaller units is much less than the larger disks; hence they are much quieter in operation. The resulting rectified high-voltage current is exactly the same as that produced by a single disk and single transformer.

CROSS-ARM RECTIFICATION.

The cross-arm type of rectification utilizes a long shaft attached to the end of the synchronous motor. This shaft is constructed of nonconducting material. At suitable intervals extending entirely through the shaft, there are cross-arms of conducting material. These revolve in relation to conductors or sectors connected with the terminals of the transformer and with the terminals of the *x*-ray tube. In the cross-arm type of rectification the rectifier operates in more than one plane. Except for this its action is the same as that of the disk-type rectifier. If one understands the operation of the latter, by examining the diagrams in Fig. 26, A and B, the action of the cross-arm type will be made clear.

VALVE-TUBE RECTIFICATION.

A valve tube is constructed and functions much like a hot-cathode x-ray tube. Each has a fusiform, cylindrical, or spherical glass bulb in which the vacuum is as complete as possible. Each has two arms or ends, one containing the cathode, the other the anode. In each, the cathode is a filament of tungsten wire connected to two wires that are brought out of the cathode arm to an electrical connection on its end. In each, the heated tungsten filament in the tube provides electrons by thermionic emission to carry a high-voltage current through the tube from the cathode to the anode.

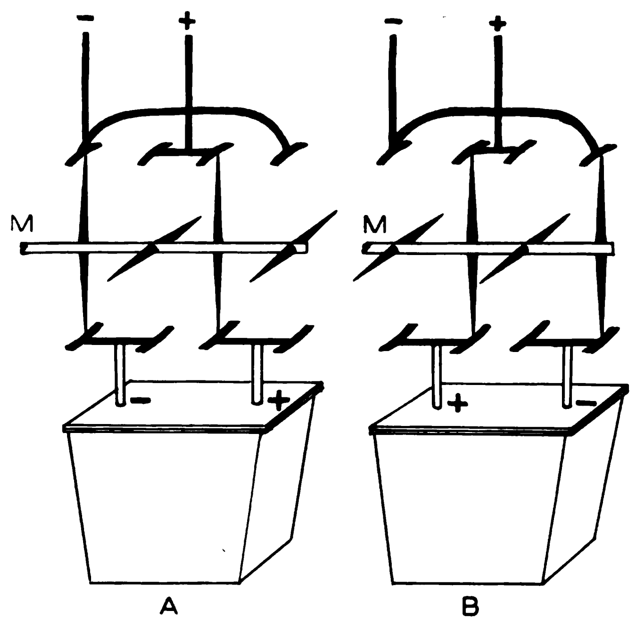

FIG. 26.—Cross-arm rectifier. A, the left terminal of the transformer is negative; B, the right terminal of the transformer is negative; M, end of shaft to which motor is attached.

In a valve tube the filament is in the form of three or four loops, or in a spiral filament in the long axis of the tube, or it may be in the form of one or more spirals at right angles to the long axis of the tube. The anode may be in the form of a thick rod with a flat surface parallel with the looped or transverse spiral filament; it may be in the form of a metal cylinder surrounding a longitudinal spiral filament; or it may even be a metal portion of the tube itself around the filament.

The filament of a valve tube carries a low-voltage current, 16 volts or less, with a rather high amperage, as much as a 14-ampere

current being required for some operations. The supply of the filament is provided by a separate step-down transformer constructed much like the transformer for the filament of an x-ray tube. Each valve tube is connected with a transformer. In a rectifier with 4 valve tubes there may be a separate transformer for each tube or there may be 3 transformers, 1 for each of 2 tubes, the third supplying the other 2 tubes. In an arrangement like that shown in the diagram in Fig. 30, tubes A and B would each require a separate transformer. Tubes C and D have their cathode ends connected and they may be supplied by the same filament transformer. These transformers are usually placed in the same case and insulated with the same oil as the high-tension or x-ray transformer. The valve tubes may be mounted on top of the transformer case or they, too, may be placed inside the transformer case and insulated by the oil in it.

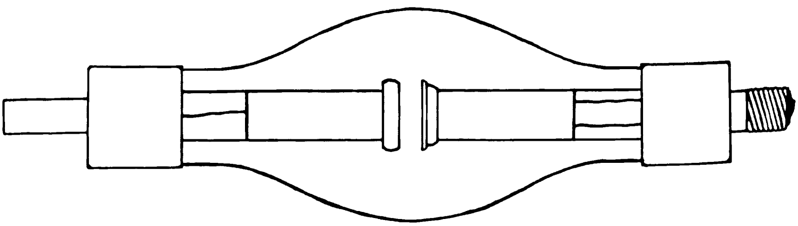

FIG. 27.—One kind of valve tube.

In a valve tube the filament is large and it is heated to a high temperature. This provides an excess of electrons, carrying the high-voltage current across the tube without much drop in voltage. In fact, the more efficient valve tubes cause the least voltage drop. The electrons from the filament are not focused on any limited area of the anode but spread out over a considerable surface. A valve tube is not operated at saturation (see p. 37). In most apparatus provided with valve tubes, provision is made for changing the valve-tube current for different high-voltage milliamperages: high amperage current through the tubes when high milliamperages are to be carried, and lower tube amperages for lower milliamperages. In apparatus that permits of very high milliamperages, a special booster circuit may provide a very high tube current for the short periods of time that the high milliamperage is passing through the tube.

The rectifying action of a valve tube depends on the emission of electrons by the heated filament. If a high-voltage alternating current be applied to such a tube, during those half waves when the cathode end of the tube is negative and the anode positive,

electrons will be available to carry the current through the tube. During the other half waves the anode end of the tube will be negative and the cathode positive, electrons will not be available, the current will not pass, and these half cycles will be stopped or suppressed.

The simplest form of valve-tube rectification of current from the high-tension transformer of an *x*-ray machine is by means of a single valve. This tube may be connected in the high-voltage circuit of the transformer in series with the *x*-ray tube, or it may be

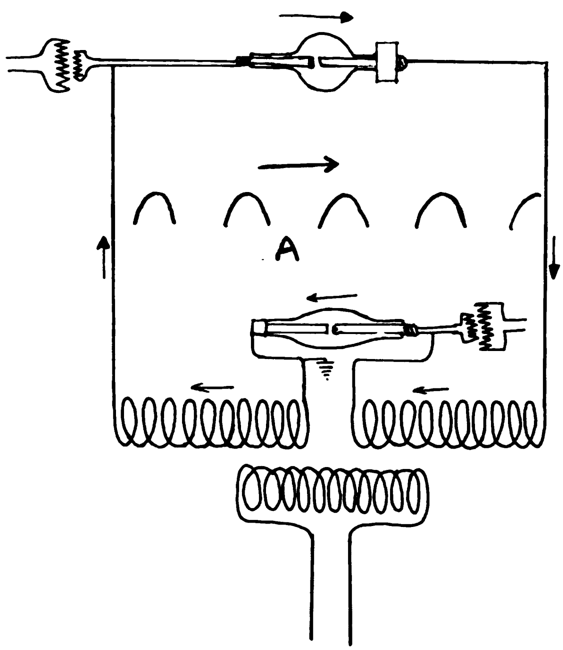

FIG. 28.—Diagram illustrating half-wave rectification with one valve tube connected in series with the *x*-ray tube and placed in the center of the secondary winding of the transformer. Insert A, half-cycle waves flowing in one direction, the opposite half-cycles are suppressed. Compare with Fig. 24.

connected to the middle of the secondary coil of the transformer. In either location the action is the same; those half cycles passing from the filament to the anode of both the valve and *x*-ray tubes are permitted to pass (Fig. 28). The opposite half cycles are suppressed. A hot-cathode *x*-ray tube has much the same action (see p. 60), and is used to rectify the current in unit-type or self-rectifying apparatus. The capacity of the self-rectifying apparatus is limited. The addition of a single valve tube relieves the *x*-ray tube of some of the strain of the inverse current and permits the use of higher energies. An *x*-ray machine with a single valve is said to

be a half-wave apparatus and the current is spoken of as half-wave rectified current.

Two valve tubes have not been used economically for full-wave rectification for roentgenographic equipments. In half-wave machines equipped with shock-proof cables from the transformer to the x-ray tube, two valve tubes are sometimes used. One of these is in series with the x-ray tube at the beginning of the cable to the cathode of the tube, the other in series with the tube at the attachment of the anode cable to the transformer. The three tubes

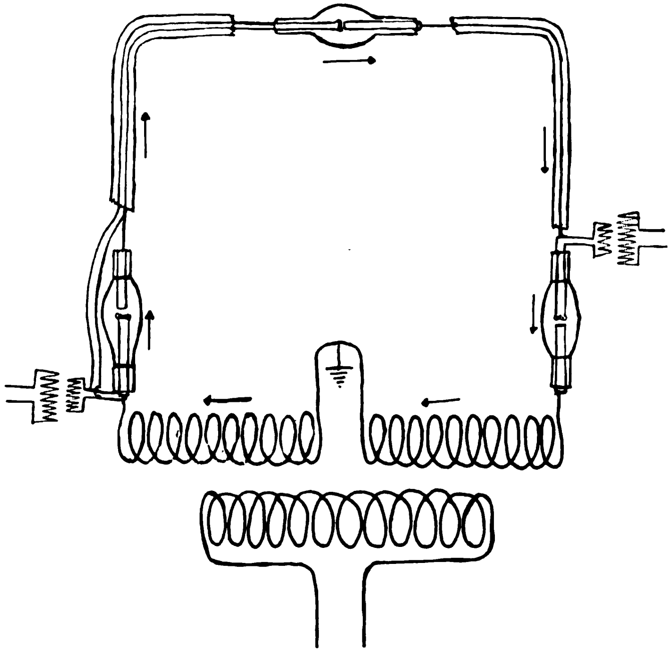

FIG. 29.—Diagram illustrating half-wave rectification with two valve tubes. The high-voltage leads are shock-proof cables. The valve tubes are connected in series with the x-ray tube at the ends of the secondary coil of the transformer. The valve tube in the anode side of the high-voltage circuit protects the cable from the inverse voltage and prevents breakdown.

in series permit passage of half waves from the cathodes to the anodes of the tubes, but suppress the opposite half waves. This arrangement removes the strain of the inverse voltage on the shock-proof cables, particularly the one to the anode of the tube, protects the cables from breakdowns, and permits the use of higher milliamperages and voltages through the x-ray tube (Fig. 29).

Rectification with 4 valve tubes is perhaps the most efficient type of rectification obtainable. Fig. 30 shows the arrangement and illustrates the action of this type of rectifier. The opposite

electrodes of two tubes, A and D, are connected to one terminal of the high-tension transformer; and the opposite electrodes of two other tubes, B and C, are connected to the other terminal. The anode ends of tubes A and B are connected together and to the cathode terminal of the *x*-ray tube; the cathode ends of tubes C and D are connected together and to the anode of the *x*-ray tube.

In Fig. 30, A, the course of the current is indicated for those half cycles during which the right-hand terminal of the transformer is negative. From the transformer terminal the current passes through tube A from the cathode to the anode, then through the *x*-ray tube. From the anode end of this tube it will pass through valve tube C back to the transformer. From the diagram it will be noted that valve tube D is placed so that it might offer a path back to the

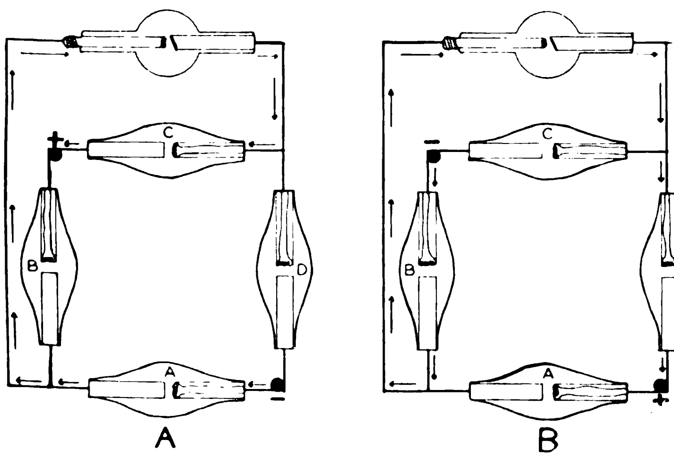

Fig. 30.—Valve-tube rectifier with four tubes. The arrows indicate the direction of the electron flow.

transformer, but during this half cycle this tube will be of the same potential as tube A, its anode end will be negatively charged and will resist the passage of the current.

When the transformer has changed its polarity and the left-hand terminal is negative, the course of the current will be that illustrated in part B of the figure. It will pass through valve tube B, then through the *x*-ray tube and back to the positive terminal of the transformer through tube D; tube C, being of the same potential as B, will resist the passage of the current.

Noiselessness, cleanliness, and freedom from radio interference in valve-tube rectified *x*-ray equipments are advantages that have made mechanically rectified machines obsolete. At the present time all equipment being manufactured and sold is of the valve-

tube or self-rectified type. However there does not appear to be enough difference in the x-ray output from equipments using the two types of rectification to favor one over the other. Fig. 31 is a diagram illustrating the similarity in the rectifying action of valve tube and mechanical rectifiers.

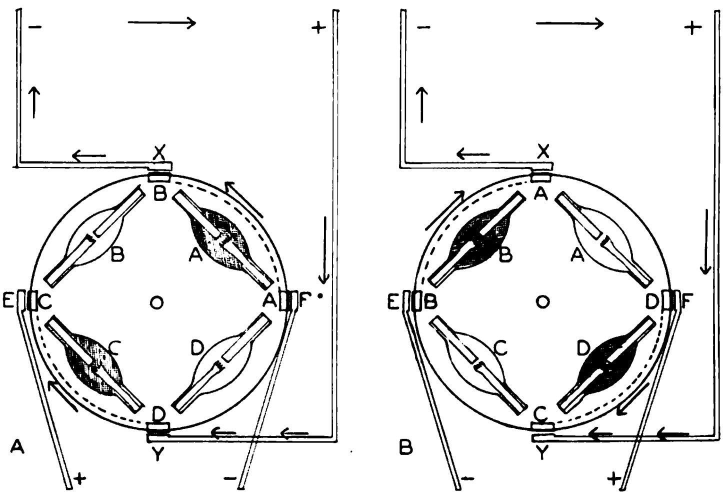

FIG. 31.—Comparison of disk-type mechanical and valve tube rectification of the high-voltage current. *A*, the current passes from the negative pole of the transformer to F, then from A to B along the edge of the disk, or through valve tube A; from B to X, then through the x-ray tube and back to Y; from D to C along the edge of the disk, or through valve tube C; from C to E to the positive pole of the transformer. *B*, the polarity of the transformer has changed and the disk has revolved a fourth of a turn. The current passes from the negative pole of the transformer through E to B; from B to A along the edge of the disk, or through valve tube B; through X, through the x-ray tube and back to Y; from C to D along the edge of the disk, or through the valve tube D; from D to F to the positive pole of the transformer.

THE FILAMENT CIRCUIT.

The vacuum in a hot-cathode or electron x-ray tube is as complete as it is possible to get it. During the final stage of the exhaustion the tube is heated with a high-frequency current to drive out the air and gases contained in the metal parts and the glass. By thermionic emission, the electron supply of the tube comes from the incandescent filament, and the milliamperage through the tube depends directly on the heat of the filament. To heat the cathode filament and to control its temperature, a separate electric circuit is necessary. This is the filament circuit (Fig. 32).

Electricity for the filament circuit is obtained from the current supply or the autotransformer. It passes through a device known as the filament regulator (FR) which may be an impedance resistance, a choke coil, or a rheostat, and then through a step-down

transformer (FT). In this manner a current of low voltage and 3 to 5 amperes is delivered to the filament, the amperage being controlled by the filament regulator.

The filament regulator is mounted in the control cabinet or on the wall adjacent to it. It has a variable control so that the amperes through the filament may be altered through the entire range of fractions from 3 to 5 amperes. On many equipments there is included as a part of the instrument a filament scale with arbitrary subdivisions to make possible the repetition of a certain setting. On others a filament meter is placed in the primary circuit of the filament transformer and mounted with the other meters on the control panel.

From the regulator the filament circuit passes to the primary of the filament transformer. This transformer reduces the voltage

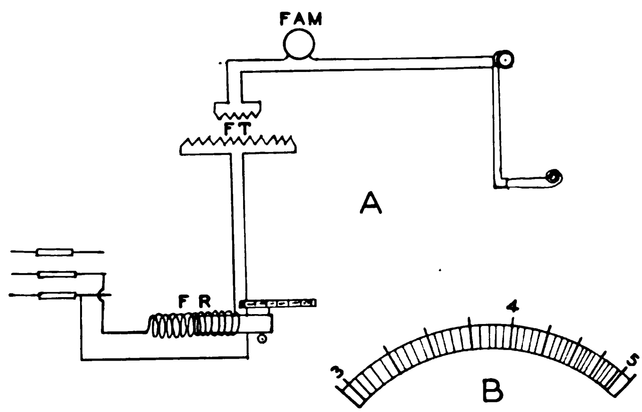

Fig. 32.—A, filament circuit of an *x*-ray machine. The filament transformer, amperemeter, and the conductors between the transformer and tube are in the high-voltage circuit also. FR, filament regulator; FT, filament transformer; FAM, filament amperemeter. B, scale of a filament amperemeter.

from 220 or 110 to the low voltage required. The secondary of the filament transformer is in the high-voltage circuit, so that the two coils of this transformer must not only be insulated from each other, but also in such a way that the high-voltage current cannot pass into the primary coil. Because it is in the high-voltage circuit, it is placed on the cabinet housing the rectifier, in the case with the high-tension transformer, or on the wall of the room.

From the filament transformer the current is carried by a complete circuit to the cathode end of the tube and through an electrical connection to the tube filament. It is a part of the overhead or aerial system. It may be made of two wires, of a metal tube for one side of the circuit, a wire within it forming the other side, or

both sides may be made of wires within a tubing overhead system. From the aerial the circuit is carried to the tube by two wires attached to spring reels to keep them taut. In shock-proof installations the circuit is carried in one of the insulating cables. This may lead either from the overhead system to the tube or directly from the transformer case to the tube. The wires, tubes, or cables also carry the cathode side of the high-voltage circuit.

Because of the low voltage in the filament circuit it is essential that the conductors be of ample capacity to carry the filament current without undue voltage drop.

A very useful instrument that is sometimes installed in the filament circuit is an amperemeter which measures the amperes of current in the filament circuit (Fig. 32). It, too, usually is in the high-voltage circuit and is mounted on insulated brackets. This instrument has a scale reading from 3 to 5 amperes, subdivided by coarse markings into $\frac{1}{4}$ or 0.25 amperes, and by fine markings into 0.05 amperes. The use of the filament amperemeter will be explained in a later section.

STABILIZATION AND STABILIZERS.

In a previous section it was stated that the electricity for the supply of an *x*-ray machine should be as free from voltage and amperage fluctuations as possible. If there be much irregularity in the supply, there may be an unpredictable inconstancy in the voltage and milliamperage through the tube, with resultant variations in the *x*-ray output. The milliamperage will vary much more than the voltage. A very small variation in filament current (measured in amperes) will have a profound effect on tube milliamperage—a variation of as little as 5 per cent in filament current may cause as much as 50 per cent change in tube milliamperage.

To prevent voltage and milliamperage variations, pieces of accessory apparatus called stabilizers have been developed. One of the first of these was a stabilizer to be installed in the high-voltage and filament circuits of an *x*-ray machine to stabilize the filament current and prevent fluctuations. In principle it is a mechanical and electrical device with an electromagnet and a vibrator capable of rapidly throwing a resistance in and out of the filament circuit, in when the current rises and out when it falls. The apparatus can be set for a desired milliamperage before the exposure starts. There is always an initial surge while the apparatus is activating, making it undesirable for short exposures. There also is some slight variations in current and voltage after the initial surge. For long exposures the apparatus is helpful in maintaining a constant filament cur-

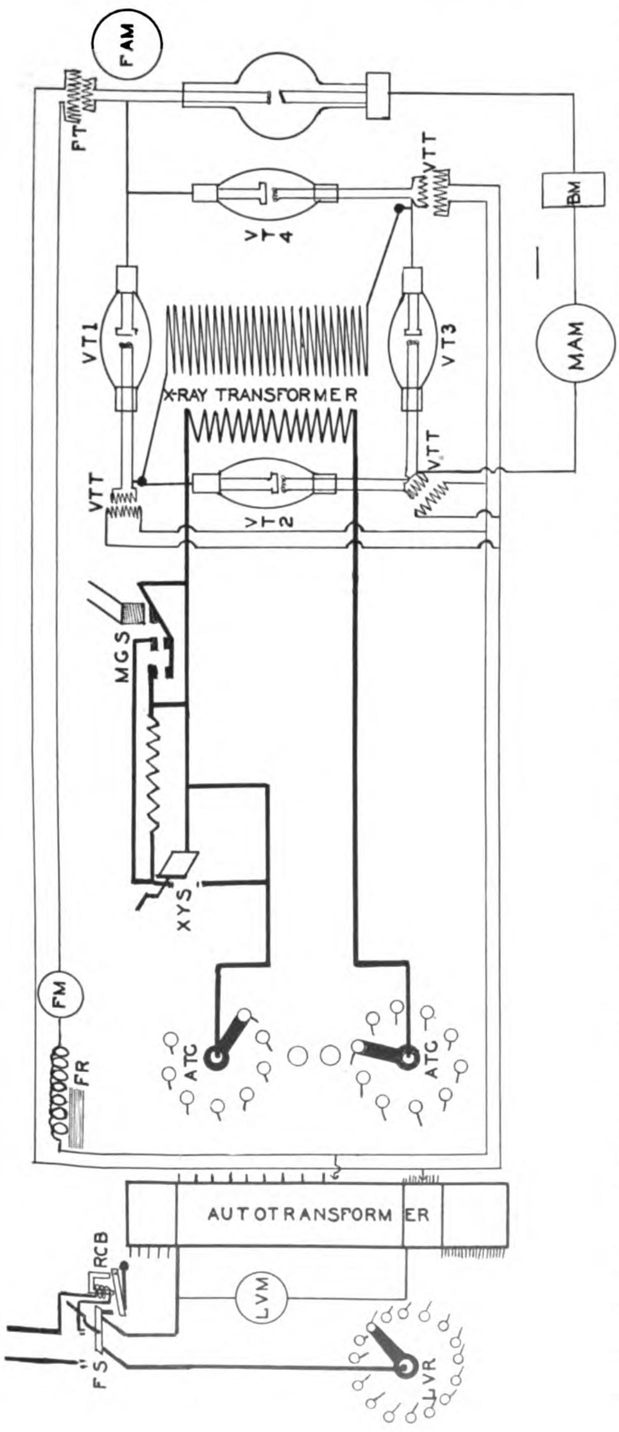

FIG. 33.—Wiring diagram of an *x*-ray machine with valve tube rectification of the high-voltage current to show the connection of the different parts. FS, filament switch; RCB, relay circuit breaker; LVR, line-voltage regulator; LVM, line-voltage meter; ATC, autotransformer control switches; FR, filament regulator; FM, filament meter; XYS, manually operated *x*-ray switch; MGS, magnetic *x*-ray switch; VT 1, 2, 3, and 4, valve tubes; VTT, valve-tube transformers; FT, filament transformer; FAM, filament amperemeter; MAM, milliamperemeter; BM, ballistic milliampere-second meter.

rent and filament milliamperage, particularly when the supply is inconstant.

A much more desirable form of filament current stabilizer is one made to be installed in the filament circuit in front of the filament regulator or control. It is a primary circuit filament current stabilizer. It is a complex piece of apparatus. It acts by providing the filament circuit with a voltage in which there is very little variation irrespective of the voltage changes that may occur in the supply line. It will compensate for voltage drops during exposures and for any incidental voltage changes that may occur. With such a stabilizer the filament current will depend on the adjustments of the filament regulator which can be determined from the filament amperemeter, a particular filament amperage giving a certain milliamperage through the tube (see p. 115).

The greatest development in stabilizing apparatus has come in recent years in the form of so-called automatic control panels or boards. Apparatus is included in these by means of which the controls can be set for a certain milliamperage and voltage and these values will be delivered to the *x*-ray tube with remarkably little variation or fluctuation. This development in automatic stabilized control is probably the outstanding improvement in *x*-ray apparatus since the development of rotating-anode *x*-ray tubes.

Fig. 33 shows a complete wiring diagram of an *x*-ray machine with a valve-tube rectifier, included especially to illustrate the connections of the different parts.

WITH DIRECT CURRENT.

A transformer requires alternating current for its operation. In localities where the electric supply is direct current, this must be changed to alternating by a rotary or motor converter before it is sent into the high-tension transformer of an *x*-ray machine. A machine of this sort requires a stable direct current supply. If the voltage be irregular the speed of the converter will be uneven, with corresponding changes in the frequency of the alternating current. This will have a decided effect on the *x*-ray output of the equipment. With mechanical rectification, the rectifier usually is mounted on the shaft of the converter making the synchronous motor unnecessary. Since the polarity of the rectifier and the transformer in such apparatus is always the same, the polarity circuit also is eliminated. With these exceptions the operation of a machine using direct current is the same as that of one using alternating current.

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CHAPTER III.

ROENTGEN-RAY MACHINES (CONTINUED).

THE UNIT TYPE OF ROENTGEN-RAY MACHINE.

IN a hot-cathode or electron type of x-ray tube the electrons necessary to carry the high-voltage current from the cathode to the anode are given off by the heated tungsten of the cathode filament (see p. 37). As long as the anode of the tube remains at a temperature below the point of electron emission, the tube will act like a valve tube and may be used directly attached to the terminals of a suitable high-tension transformer without previous rectification of the current. The radiator type Coolidge tube was especially designed for this purpose. The heat from the tungsten button which forms the anode is conveyed through the copper anode stem to the copper radiator which cools in the air. When operated directly from the terminals of a transformer and within its rating, this tube will suppress that part of the high-voltage alternating current which attempts to pass from the anode to the cathode, while the electrons from the cathode filament will carry the other half waves in the opposite direction for the production of Roentgen-rays. Formerly the radiator type Coolidge tube was the only tube that had this ability. Now, most types of hot-cathode tubes, whether cooled by means of a radiator, a water reservoir, or by immersion in oil, have this property.

The ability of the Coolidge radiator tube to rectify the current from a high-tension transformer, by suppressing or stopping half the waves, made possible the development and introduction of smaller transformer type x-ray machines. These are known as unit type machines, or as self-rectifying machines, and the current is called self-rectified current. The adaptability of other forms of tubes to this purpose, notably the smaller oil-immersed tubes, and the increased speed of intensifying screens and x-ray films have increased the usefulness of these equipments.

Mobile units for bedside work in hospitals, all of the portable x-ray machines, all of the special dental machines, all machines having the tube and high-tension apparatus oil-immersed in a single container, all fluoroscopic units, and many other simple installations are of the unit type. The essential parts of these machines are the same and they have much the same operating characteristics. There are, however, considerable differences in their capacities and many differences in the details of their construction.

Common with the larger forms of equipments, the apparatus of the unit type is often in two parts. One of these includes the control devices with the switches and meters mounted on a suitable control panel. The high-tension transformer and the filament transformer are separate and in the same transformer case. The two parts are connected by insulated cables. In the mobile units the control panel is on the top with the rest of the equipment arranged within a box-like housing. The shock-proof forms are of two types. One has a separate control stand with the high-tension apparatus and tube immersed in oil in a single housing. This may be attached to an upright, be suitably counterbalanced, movable on rails, and so arranged that it readily can be adapted to its different uses. The other form of shock-proof unit is like the mobile unit with shock-proof cables leading to an oil-immersed tube or to an air-cooled tube inclosed in a shock-proof housing.

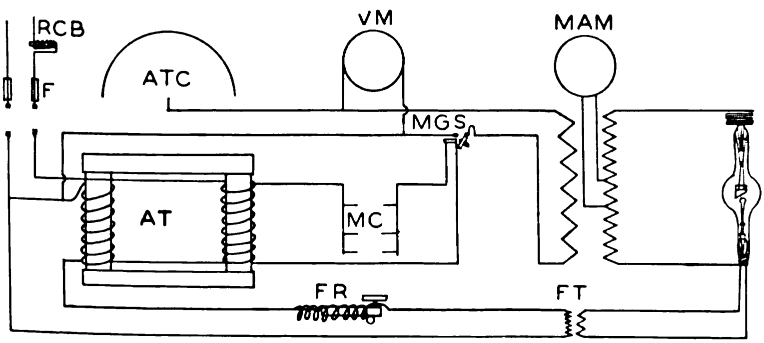

FIG. 34.—Wiring diagram of a unit type *x*-ray machine having a magnetic *x*-ray switch. RCB, relay circuit breaker; F, fuses; AT, autotransformer; ATC, autotransformer control; VM, voltmeter; MGS, magnetic *x*-ray switch; MC, circuit of the magnetic switch; FR, filament regulator; FT, filament transformer; MAM, milliamperemeter.

In unit type machines the rectifier and its associate circuit are not required. Most of the other parts of the transformer type described in the preceding chapter are represented. These include the supply line and its current, the primary circuit, the secondary circuit, and the filament circuit, with their various instruments and apparatus.

Unit type machines may require either a 110- or 220-volt supply. Some of them are so constructed that by a simple adjustment either voltage may be used. If available, a 220-volt supply is preferable. If such a machine is to be installed in one room and not used as a mobile or portable unit, a separate step-down transformer for its supply is desirable. The supply of a machine adapted to 110 volts

may be obtained from the lighting circuit of the building in which it is used.

As in larger machines the primary circuit begins in the supply line and includes the primary coil of the high-tension transformer. In some unit type machines, especially dental units, voltage control devices are omitted from the primary circuit. In these there is no provision for varying the voltage in the primary circuit; hence there is only a single voltage available in the secondary circuit. In other machines an autotransformer is included. The taps from the autotransformer may give three voltage selections in the primary circuit, those corresponding to a low, a medium, and a higher voltage in the secondary circuit; or the autotransformer may be more complicated, giving as many as 20 steps in the primary and secondary circuits. In some self-rectifying equipments the autotransformer may be like those in larger machines, giving steps in the primary corresponding to those of 1 or 2 peak kilovolts in the secondary circuit. The details of the gradations in the autotransformer in any equipment must be learned from the manufacturer.

The primary circuit also may have a primary voltmeter and some form of *x*-ray switch. The voltmeter usually is connected between the autotransformer and the *x*-ray switch and serves as a very useful indicator of the primary and secondary voltages. As in the larger machines a magnetic *x*-ray switch or contactor, which may be operated by a hand switch, a foot switch, or a timer, is the best form. A relay circuit breaker is an important safety device sometimes installed in the primary circuit.

Because of the limited capacity of the unit type of machine, the step-up or high-tension transformer is usually small and compact. The core type oil-immersed form most often is used. The construction of the secondary circuit depends on the type of machine and kind of installation. The terminals of the secondary coil of the transformer may be brought out of the case through rigid insulators. In the mobile unit the insulators often are continued to a height of 5 or 6 feet and are curved downward at the end. At their ends are attached the spring reels on which are wound the wires reaching to the tube terminals. In shock-proof units, flexible conductors may carry the high-voltage circuit to the tube housing. In permanent installations the transformer may be mounted on the wall or under a fluoroscopic table with a modified and usually simple overhead system continuing the circuit to the tube in the tube stand or fluoroscope.

The milliamperemeter is connected to the neutral part of the high-tension transformer in such a way that it will register the milliamperage, but being at ground potential, there is no danger of

high-voltage shock from it. It is mounted in the control panel. In a self-rectifying or half-wave rectifying x-ray machine, every other half cycle passes through the x-ray tube and produces x-rays. The intervening half cycles are suppressed. The moving parts of the milliammeter are not delicate enough to respond to these rapid changes in milliamperage. For this reason the milliammeter only registers an average or mean milliamperage that is a fraction, half or less, of the highest that passes through the tube. This is one of the reasons for the diminished capacity of this kind of apparatus when it is compared with full-wave rectification.

The filament regulator and sometimes a filament meter are mounted in the control panel. The filament transformer is placed in the same container and insulated by the same oil as the high-tension transformer. The filament circuit is completed by two electrical conductors leaving the transformer case and leading to the cathode of the tube. The cathode of the high-voltage circuit is made up of the same leads.

The available milliamperages vary with the equipment and the tube. In some, 10 or 15 milliamperes is the highest permissible; in others milliamperes as high as 30 or more may be used. Apparatus has been manufactured with self-rectifying tubes delivering as high as 100 milliamperes at voltages as high as 85 peak kilovolts. However, apparatus with such high capacity preferably should be half-wave rectifying with one or two valve tubes to assist the x-ray tube in suppression of the inverse currents.

When used for the purposes for which they are intended and operated within their rated capacity, the unit types of x-ray machines are excellent apparatus. Except the low-voltage dental and portable units, these machines may be operated up to 5 milliamperes and 85 to 89 peak kilovolts for fluoroscopy. For roentgenographic work they may be operated to their full rated capacity in both milliamperage and voltage. High-speed intensifying screens and more sensitive x-ray films have increased the usefulness of unit type equipments. When compared with machines capable of full rectification of the secondary current and even with some of the older ones with mechanical rectification, most self-rectifying units have a limited output. High-speed roentgenography, especially important in the examination of the chest and gastrointestinal tract, often cannot be satisfactorily done with unit type equipment; neither is it as efficient as full-wave apparatus for exposures using a Potter-Bucky diaphragm. For these reasons half-wave rectifying apparatus probably is unsuited for a laboratory doing all kinds of diagnostic roentgenological work.

An x-ray machine is a complicated piece of equipment composed

of many different interrelated and coördinated parts. As far as is possible, any person attempting to operate one should be familiar with the different parts, their functions, and their operating characteristics. Students in *x*-ray technique should learn about all available kinds of *x*-ray machines and apparatus, not merely those with which they are immediately concerned. To aid in studies of this kind, an outline has been prepared. All the parts listed will not be found on every *x*-ray machine, particularly the smaller and simpler outfits; many or most of them will be found on the larger and more complicated apparatus. Using this outline for review, for study of unfamiliar equipment, for the preparation of notebooks, etc., will be found most helpful.

I. Supply Line
    A. Kind of current supply, voltage, frequency, amperage, etc.
    B. Lead-in or power transformer, location, capacity, other uses
    C. Lead-in or supply line, length, size, etc.
    D. Motor-generators, rotary converters, etc.
    E. Supply-line switches, fuses, and safety devices (location, uses)
II. Low-voltage Circuits
    A. Primary *X*-ray Circuit
        1. Voltage control
            a. Rheostat, uses; advantages and disadvantages
            b. Autotransformer, uses; advantages and disadvantages, voltage range, autotransformer steps, voltage intervals
            c. Voltage stabilizers and regulators
            d. Line-voltage correction and regulators
        2. Measuring instruments
            a. Primary voltage meters, calibration, and scale readings
            b. Illuminated autotransformer dials
            c. Line-voltage regulator
            d. Line-voltage meter
        3. Switches and operating devices
            a. Contactors: magnetic, oil immersed, vacuum tube
            b. *X*-ray switches: manual, foot, Bucky, spot-film
            c. Timers: clock-work, synchronous, impulse, construction, range, and accuracy
            d. Safety devices
    B. Filament
        1. Voltage and amperage range
        2. Filament regulator
        3. Measuring instruments: filament scale, filament meter, calibration
        4. Filament step-down transformer, location, ratio, insulation
        5. Stabilization, primary or secondary circuits
III. High-voltage Circuit
    A. *X*-ray Transformer: type, construction, ratio, insulation, location
    B. Rectification
        1. Self-rectification, limits
        2. Mechanical rectification

- *a.* Type, single or double disk, cross-arm
- *b.* Synchronous motor, speed, starting connection
- *c.* Polarity commutator, polarity indicator, polarity switch

3. Valve-tube rectification
   - *a.* Valve tubes, construction, characteristics, circuits
     - Single tube, half-wave rectification
     - Two tubes, half-wave rectification
     - Four tubes, full-wave rectification

C. Overhead and High-voltage Leads
   1. Construction, shock-proofing, cables, etc.

D. *X*-ray Tube
   1. Types: Coolidge, hot-cathode, rotating anode
   2. Filaments: single, double, coiled, elongated, focusing devices
   3. Anode and focal spots: material, actual and projected shape and size, capacity
   4. Cooling: radiation, radiator, oil immersion, water cooled, oil cooled, fan
   5. Housing: ray proofing and shock proofing

E. Secondary or High-voltage Current
   1. Transformer and tube limits; voltage range and intervals, milliamperage limits
   2. Controls, autotransformer, filament regulator
   3. Measuring instruments
      - *a.* Voltage: prereading meters and calibrations
      - *b.* Spark gaps
      - *c.* Milliamperage: milliamperemeter, ballistic milliampere-second meter

CARE OF A ROENTGEN-RAY MACHINE.

An *x*-ray machine requires constant care. It should be kept clean. High-voltage current will attract dust particles from the atmosphere, and dust will collect on all parts of the machine that are not of shock-proof construction. A coating of dust is apt to cause a current leak or a short circuit along insulating brackets, insulators, across or around the edge of a rectifying disk, or along the arms or shaft of a cross-arm rectifier. Dust on overhead wires or tubes will cause variations in the filament current with resulting fluctuations in the milliamperage through the tube; dust on rectifier and *x*-ray tubes will make them more apt to puncture. In localities where the air is very smoky or dusty, it may be necessary to clean the entire apparatus each day.

Oiling also is important. The motor of a mechanical rectifier should be oiled at least once a month, and the motors on motor-driven tables, synchronous timers, etc., should receive proper care. At the same time brushes and commutators should be inspected and cleaned. Parts of the machine where metal rubs against metal

should be oiled occasionally. If the plated and polished parts of the machine are rubbed now and then with an oiled rag or with suitable polish, rusting of the metal and dimming of the polish will be prevented.

If an x-ray machine be kept clean and well oiled, it will last and give good service for years.

DANGERS.

There are three dangers constantly present in an x-ray laboratory. One of these is the overexposure of patients with x-rays producing some degree of radiodermatitis; another is the liability of operators of x-ray machines to injuries of the superficial tissues and derangements of internal organs, especially changes in the blood from long-continued exposure to small amounts of Roentgen-rays, and the third is the danger from electric shocks to operators, spectators, and patients.

Overexposures in diagnostic work are so uncommon that many liability insurance companies do not require a physician to pay an extra premium for liability protection.

Turnbull and Leddy conducted experiments to determine the amount of radiation reaching the patient's skin in various roentgenographic exposures. By dividing the number of roentgens known to produce a threshold erythema dose by the number delivered with each type of exposure, the number of such exposures that could be made without danger was determined. Twenty-five exposures of teeth and 29 of the sinuses were the smallest number, but they say that these, because of danger of epilation should be reduced about a third. Thirty-one pyelograms, 125 films of the colon, 375 of the stomach, and 938 of the thorax, are examples of permissible exposures of other portions of the body. From these results it is apparent that any skin damage from roentgenographic exposures is extremely unlikely.

Most overexposures to x-rays from diagnostic procedures have come from fluoroscopic examinations. In the average fluoroscope the distance from the anode of the x-ray tube to the patient's body surface is much less than that used in radiographic work. Interest in some unusual phenomenon or the demonstration to visitors of the equipment or the examination of the patient may lead the operator of the machine to prolong the exposure unnecessarily and cause a reaction on the patient's skin. Especially to be guarded against is the prolongation of the x-ray examination when using a fluoroscope in the reduction of fractures or in the removal of foreign bodies.

Turnbull and Leddy found that with 85 kilovolts, 5 milliamperes of current, a filter equivalent of 1 millimeter of aluminum, and the tube anode 15 inches from the skin, a threshold erythema dose would be delivered in twelve and a half minutes. Stevenson and Leddy conducted further experiments into the dangers of reducing fractures under fluoroscopic control. Using much the same set of factors they found that an erythema dose would be delivered in seven minutes and forty-five seconds if the apparatus is operated without a filter. The use of 1 millimeter of aluminum increased the time to over fifteen minutes, the use of 2 millimeters of aluminum increased the time to twenty-four minutes; the amount of *x*-rays would be diminished by using a lower voltage or a lower milliamperage. Cilley, Leddy, and Kirklin conducted an elaborate series of experiments to determine possible dangers to operators in making fluoroscopic examinations. They emphasize the importance of short examinations, the smallest effective beam, utilization of the protection of the barium in the stomach and intestine to protect the hands during palpation, and freedom from other exposures.

Taft conducted experiments to determine the amount of stray radiation resulting from different kinds of examinations. He found that enough radiation reached an operator's body during fluoroscopy to warrant wearing an apron or using some other protection, but that scattered radiation from radiographic exposures, not in the direct path of the rays, was negligible. However, he favors a lead screen for protection of a technician if any considerable amount of *x*-ray work is done.

As general precautions it may be said that examinations, partly or all fluoroscopic, should not be repeated soon after one has been made, an equipment should never be operated without a filter of at least 1 millimeter of aluminum or its equivalent, an operator of an *x*-ray machine should never place any part of his body in the direct path of an *x*-ray beam, and that, during fluoroscopy, the examinations should be made as quickly as possible with the smallest beam of rays. These precautions apply to the small, shock-proof types of equipment as well as the larger apparatus. In fluoroscopy it is advisable to have some sort of protection for the body, and a lead screen in a radiographic room is an additional protection.

The recommendations of the different committees that have investigated this subject have been published so often that it is not necessary to repeat them. Those of the Council on Physical Therapy of the American Medical Association were published in the *Journal of the American Medical Association.*

Unless shock-proof apparatus be used, the danger from electric shocks is constantly present. A serious electric shock may result

from contact with or too close proximity to any part of the high-voltage or secondary circuit. Since this current will jump an air space that is one-half the spark gap length, even with the middle of the transformer grounded, and the full length of the spark gap when the transformer is not grounded, actual contact with the wires or tubing is not necessary. To prevent electric shocks, the operator should know when and where such shocks may occur and always be on guard against them. With a machine equipped with an overhead system, the milliamperemeter, the filament amperemeter, and the wires from the overhead to the tube are the parts of the machine from which shocks usually come. A machine with a low position of the secondary circuit, either of the unit or larger type, is more dangerous than one with an overhead system.

To prevent accidental electric shocks, there are certain precautions that should be observed. If these be practiced at the beginning, they soon become a matter of habit and are repeated automatically and often unconsciously. Perhaps the most important of these is deliberateness. While a very rapid exposure often is advisable, hurrying in a laboratory is never necessary. There are so many factors in an *x*-ray exposure that enough time should be taken to think out each step in advance.

A laboratory should never be crowded with spectators. Even if the entire family accompanies the patient and each member shows a great deal of interest in the examination, it is a good practice never to admit more than one spectator to the laboratory. It is best to place this one person in a chair and caution him to remain seated. Overhead wiring to a vertical fluoroscope usually is on the operator's left, so that visitors during a fluoroscopic examination should always be kept on the operator's right-hand side.

Two persons should never attempt to operate, adjust, repair, or otherwise use or work on an *x*-ray machine at the same time. Many accidental electric shocks have been due to violation of this precaution.

Before each exposure is begun, an operator should make it an inviolable rule to see that all high-voltage wires are at a safe distance from the patient, the tube stand, other persons in the laboratory, and himself. The tube terminals and wires should be distant from the patient at least twice the length of the spark gap of the current through the tube. It is best to develop a habit of seeing that this precaution is observed as the last act before each exposure is begun.

If the machine has in the primary circuit a main switch, a safety switch, or a polarity switch that can be opened with the motor running and the filament lighted, the maximum degree of safety can be assured if this switch be closed only during actual exposures.

This is especially true when an examination is being made requiring multiple exposures and considerable adjustment of the tube. In operating a machine so equipped, a habit can easily be formed of closing this switch just before an exposure begins and opening it just after one is completed.

Foot switches on the floor of the *x*-ray room are a source of some danger. These should have a safety switch disconnecting them when not in use, or they should be placed in some position free from danger of being accidentally stepped on.

TROUBLE HUNTING.

Breakdowns of an *x*-ray machine causing annoyances and interruptions in service may occur at any time. Fortunately most of these are of little consequence and if detected can be repaired in a short time. Most often they are caused by a loose or broken connection, a blown fuse, or a short circuit—contact of two bare wires. Trouble in shock-proof apparatus with an oil-immersed tube or in one in which the tube and transformer are in the same housing requires the help of an expert service man. In other forms of equipment the operator may be able to locate and remedy most minor troubles.

To do this some knowledge of the wiring of the machine is necessary. This should include the primary circuit from the supply-line switch to the high-tension transformer, the rectifier circuit from the supply line to the motor or rectifier tubes, the circuits energizing the magnetic *x*-ray switch, and the filament circuit from the supply line through the filament regulator and transformer to the cathode filament. The fuses for these different circuits usually are located together on a special board in the control cabinet or panel and often are labeled so that those for the different circuits can be identified.

A short circuit in any of these lines, except the 12-volt filament line, will cause a flash with some corrosion and heating of the wires and will blow a fuse. The blown fuse will be slightly heated which makes it easy to locate immediately after the accident. If the fuse be replaced and the current again turned on before the short circuit has been repaired, another blown fuse will result.

Occasionally a fuse will be blown from a temporary overload without a short circuit. Blown fuses can be detected by the heating of the fuse or by means of a test-lamp. A test-lamp for use on a machine receiving a 220-volt current should have a 220-volt bulb. Such a bulb will light to full brilliancy at 220 volts and to approximately one-half that with a current of 110 volts. If a current of

220 volts be sent through a bulb of smaller capacity, the filament will be melted.

The method of using a test-lamp can be explained by referring to the diagram in Fig. 35. S represents the lines leading from the supply line and F and F′ are the fuses. If the test-lamp lights when connected across A and B, it indicates that current is reaching that point. If the lamp lights when connected between C and D, the fuses are intact; if it does not light, then one or both of the fuses have been blown. By then connecting the lamp between A and D and between B and C, the trouble can be located. If neither of these connections causes the lamp to light, then both fuses are bad; if it lights when connected between A and D and does not when connected between B and C, then fuse F has been blown. If fuse F′ be bad, the lamp will not light when connected across A and D.

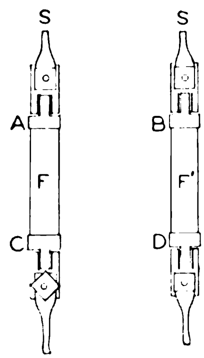

FIG. 35.—A diagram illustrating the method of testing fuses with a test-lamp. The explanation is given in the text.

A loose or broken connection in the primary circuit is very uncommon. A loose connection will cause fluctuations in both the voltage and milliamperage of the high-voltage circuit. With a break in the primary circuit there will be no high-voltage current at all. A loose connection always is accompanied by some sparking which will heat the wires and attachments near it and very often will melt the wires, completely breaking the circuit. A loose connection can usually be found if the current be turned on for some time, then shut off, and the wiring carefully gone over for a heated place.

A broken connection in the primary circuit is much more difficult to find. It is first necessary to know the condition of the magnetic switch. If this be in good working order, then connect a test-lamp between the wires of the primary circuit at the place they enter the transformer. An attempt to energize the tube in the usual way will show by the lighting of the lamp whether current is passing through the primary circuit. If the lamp does not light, there is a break in the circuit; if it lights, the trouble is elsewhere. In case a break is indicated, then it becomes necessary to test all the connections of the primary wiring.

Breaks in a circuit energizing a magnetic switch are probably next to the most common kind of trouble with an x-ray machine. These usually are due to a break in the wires at or near their connection to a foot switch, a hand switch, or a hand timer. At these places frequent bending of the wires causes them to be broken.

Many magnetic switches have more than one circuit energizing the magnet; if one does not function and the others do, the trouble can easily be located.

Trouble in the motor circuit may be due to a blown fuse, worn-out brushes, brushes that make poor contact with the commutator, or occasionally to a burnt-out centrifugal switch in the starting circuit of the motor. The brushes in a motor so equipped should be periodically inspected to see that they are in good condition and making good contact. At the same time it is wise to clean the commutator with a cloth dampened with kerosene, or with a piece of fine sandpaper. A bad centrifugal switch must be replaced. In case the polarity indicator fails to register, the trouble most often is caused by an accumulation of débris on the polarity commutator so that the brushes make poor contact. Cleaning the commutator and the brushes remedies the trouble.

Loose connections or breaks in the filament circuit are the most common form of trouble with *x*-ray machines and easily form more than one-half of such difficulties. A loose connection will cause a marked variation in the milliamperage through the tube; a broken connection will keep the filament from lighting. These troubles may be in the circuit between the supply line and the filament transformer, but most of them are between the transformer and the tube. With the filament circuit closed, if a spark can be obtained in the secondary circuit of the filament transformer, either by touching the wires together or by making a short circuit between them with a piece of copper wire, then the trouble is between the transformer and the tube. Since this current is of low voltage, there is no danger of getting even an unpleasant shock from it, but the operator must be quite certain that the high-voltage current is off.

Trouble in the primary of the filament circuit should be looked for in the same manner as in the primary circuit. That between the transformer and the tube may be sought by testing the wires by means of a spark between them. If a short circuit be made between the reels and a spark does or does not occur, it at once becomes apparent whether the break is between the transformer and the reels or between the reels and the tube. If in front of the reels, the most probable place is in an overhead switch. Most often breaks are in the wires leading to the filament connector at the cathode end of the tube. At this place the wires often are bent and always are taut, making them more likely to break here than elsewhere.

Fluctuations of major extent in the milliamperage through the tube indicate a loose connection in the filament circuit. To locate such trouble Horsley recommends that the filament be lighted to

full brilliancy and left on for some time. Then by searching the entire circuit, cathode connector, reels, overhead switches, etc., for a warm place in the wires or tubing, the loose connection can be located.

Short circuits from the high-voltage lines to a water pipe, an electric wire, or to grounded apparatus occasionally occur. They most often are due to a sagging wire in a defective reel or to a defective insulator. Trouble in either the high-tension or filament transformer causes heating of the transformer so that the expanding oil may flow out at the top. Such troubles always are of major importance and require the services of an expert service man.

When properly used, a hot-cathode x-ray tube rarely develops defects that cause trouble. Care should be exercised never to operate such a tube at more than its rated capacity; it will give longer and better service if the voltages and amperages used be somewhat less than the limits set by the manufacturer. With use, the glass of the bulb may become purple and the anode slightly pitted, neither of which interferes with the proper functioning of the tube.

A tube may be damaged in either of two ways. If too heavy currents be used in short exposures, the tungsten of the anode either melts and cools in droplets on the focal spot or the tungsten is volatilized and settles on the inside of the glass in a black, mirror-like deposit. Droplets of tungsten on the face of the anode, especially on a line or band focus tube, will interfere seriously with the Roentgen-ray output of the tube. Metallic tungsten on the inside of the glass will make the tube more liable to puncture.

If the tube be overheated by long exposures, the copper of the anode stem is melted back of the tungsten button, causing it to bulge or crack by pressure from behind. Melted copper may spread over the anode face and be vaporized and deposited on the inside of the glass wall of the tube. When this occurs the tube has been damaged so that it can no longer be used.

A slight greenish fluorescence in the anode arm of a hot-cathode tube may be present when the tube is in operation. A greenish, bluish, or pinkish light in any other part indicates that the tube has become gassy. It is best to return such tubes for examination. An attempt to operate one that has been punctured or that is very gassy will oxidize and burn out the filament and increase the cost of repairs.

The tubes in valve-tube rectified equipment rarely cause trouble. They may become gassy or puncture just like an x-ray tube and require replacement. Any hot-cathode tube, whether an x-ray or a valve tube, has a limited life, but by proper care its usefulness may be prolonged. The chief abuses of these tubes are overloading

with energies higher than they are made to withstand and carelessness in permitting the filament to be lighted when the apparatus is not in use.

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CHAPTER IV.

ROENTGEN- OR X-RAYS.

THE NATURE OF ROENTGEN-RAYS.

THE exact position of roentgen-rays or x-rays in the world of physical phenomena has not been completely established. To explain all the collected experimental data, two distinct and different theoretical conceptions seem to be necessary. One of these, the one that is older, better known, and more generally accepted, is that x-rays are a variety of electromagnetic wave motion belonging to the same class of physical phenomena as radio waves, infra-red and ultra-violet waves, the gamma rays of radium, and the rays of visible light. In the other conception, x-rays are thought to be "chunks, packets, particles, or bundles of energy spoken of as photons, the energy associated with each photon as a quantum (pleural—quanta). X-rays and visible light are very much alike in their general properties. Perhaps the nature of x-rays can best be approached by considering them as a form of electromagnetic wave motion and comparing them with the rays of visible light.

There are many forms of mechanical wave motion that are easy to comprehend. Everyone is familiar with water waves, with the waves caused by shaking a rope or a rug, or those caused by wind blowing across a field of grain. In such waves the distance from one crest to the next, or from one trough to the next, would be the wave-length, the speed with which the waves travel would be their velocity, the number per second would be their frequency; energy in some form is necessary to start them, and energy can be transferred by them.

It is not nearly so easy to comprehend electromagnetic waves. They are described as regularly recurring variations in interdependent electrical and magnetic effects having definite wave-lengths, a certain velocity and frequency, requiring energy for their initiation, and they in turn are capable of exerting energy. A simple explanation of what is meant by variations in electrical and magnetic effects cannot be made. The details of electromagnetic waves seem to depend on a mathematical explanation that cannot be understood by one not especially trained in this field. It is possible, however, to survey some of the electromagnetic waves and gain some comprehension, at least, of their general characteristics.

Based on their wave-lengths and frequencies, electromagnetic waves can be arranged in continuous order, from the longest to the

shortest, in what is called the general electromagnetic spectrum. There is an extremely wide variation in wave-lengths of the waves included in this spectrum. The longest waves are measured in meters and centimeters, metric units of measurement that should be familiar to everyone. The shorter waves, however, are so short that their wave-lengths are not readily expressed in ordinary units of measurement. For them a special unit has been devised by a Swedish physicist named Angström. This is called an Angström Unit, and is abbreviated to A.U. This unit is one hundred-millionth of a centimeter. In decimals it may be written 0.00000001 cm. Physicists often designate an Angström unit by 10^{-8} cm.

The longest of the electromagnetic waves are electric waves and those of radio broadcasting. These waves vary in length from a few centimeters to 30,000 meters. The standard broadcast band has waves from 200 to 550 meters in length. In short-wave broadcasting, now used so effectively in transoceanic communications, the waves are only a few meters in length. Next shorter than the electric and radio waves are those of heat and infra-red waves, followed by the waves of visible light. The infra-red waves have wave-lengths from about 300,000 to 7800 A.U. which is the wave-length of the longest red waves of the visible spectrum.

If a beam of visible white light be passed through a slit and then through a prism, it will be dispersed into the colors that compose the visible spectrum with violet at one end and red at the other. This separation into colors is brought about by the segregation into certain regions of those light waves that have similar wave-lengths, wave-lengths within certain limits producing the sensation of color when striking the retina. The shortest waves of visible light are those of violet which have a wave-length of about 3800 A.U.; the longest visible light waves are those of red with a wave-length of about 7800 A.U. Only those electromagnetic waves between 3800 and 7800 A.U. produce an effect on the human retina.

Shorter than the rays of visible light are those of ultra-violet with wave-lengths from about 4500 to as short as 25 A.U. The longer of these rays produce an erythema when they strike the skin and have the power to kill bacteria. The shortest ultra-violet rays are absorbed by even the thinnest layer of air and are studied only in a vacuum.

To the same order of physical phenomena belong Roentgen-rays or *x*-rays, with wave-lengths from 300 to 0.08 A.U. At first of unknown nature which accounts for the designation by their discoverer as "*X*-rays" from the familiar algebraic "*x*", they have since been shown to have many of the properties of visible light and other electromagnetic waves. Those Roentgen-rays that are useful

in roentgenology have wave-lengths extending from about 0.4 to to 0.06 A.U.; those useful in roentgenography probably are never shorter than 0.12 A.U., the shorter rays being used only for roentgenotherapy. However, therapy apparatus is being used that produces *x*-rays from 1 to 1.6 A.U. in minimum wave-length.

The shortest of the electromagnetic waves are those of the gamma rays of radium with wave-lengths from 0.2 to 0.005 A.U. Shorter still are cosmic rays, the nature of which is still in dispute but which are usually included in the general electromagnetic spectrum.

X-rays and visible light rays travel in straight lines. In common with other electromagnetic waves they have the same speed which is 186,000 miles or 300,000 kilometers a second. Neither light waves nor *x*-rays can be deflected by a magnetic field. Light rays can be reflected by a plane surface, like a mirror; but *x*-rays cannot. Light rays can be refracted by lenses, by prisms, and by suitable gratings. Because of the short wave-lengths of *x*-rays, they can only be refracted by the gratings produced by the regular spacings of the atoms in certain crystals. Light waves and *x*-rays have a similar effect on a photographic emulsion.

X-rays are produced by the passage of a suitable high-voltage, low-amperage current through an *x*-ray tube. The passage of the current depends on the presence of electrons in the tube. In gas tubes the electrons are supplied by the ionization of the small amount of residual air or gas that remains in the tube. In the hot-cathode tube the electrons are provided by the heated filament and are focused on the focal area or focal spot of the tube by the focusing device in the cathode structure.

When the cathode of the tube is heated to incandescence, the electrons boil out of the heated metal and surround the cathode like a cloud. Since the charges of the electrons are all negative and since like charges repel each other, the electrons in the tube tend to repel each other and to keep others in the filament from emerging. This creates what is called space charge in the tube. When high-voltage current is applied to the tube, some of the voltage is required to overcome this space charge and force all the electrons from the cathode to the anode. When the space charge has been overcome and all the electrons are passing through the tube, the tube is operating at saturation. Then the voltage differences between the cathode and the anode are maximum for the impressed voltage.

The electrons crossing the tube are propelled at high speed, the velocity depending on the impressed voltage. In some experiments a speed of nine-tenths that of light has been developed. When electrons traveling at such velocity are suddenly interrupted in their course by striking a solid object, the greater part of the energy

of the electron stream produces heat, but a part of it creates x-rays which travel out in all directions with the speed of light.

The anode face, including the focal area of an x-ray tube, is made of tungsten, a metal with the atomic number 74, each atom having 74 electrons in the orbits, shells, or energy levels around the nucleus; 2 electrons in the K orbit, 8 each in the L and M orbits, and 18 each in the three succeeding orbits. The nucleus has an equal number of positively charged protons. When tungsten atoms are bombarded by the electrons of the cathode stream traveling at high speed from the cathode of the x-ray tube, a great deal of electrionic and atomic turmoil and confusion must occur.

The electrons in the outer zones of the tungsten atoms are more numerous and farther removed from the atomic nuclei. By collisions these will receive most of the energy from the bombarding electrons. Electromagnetic waves or photons produced by these collisions have low energies and will be absorbed by the target material and produce heat. Other low-velocity electrons increase the motion of the tungsten ions and electrons and also produce heat. In such ways more than 99 per cent of the total energy of the cathode stream is converted into heat.

The remainder of the electrons of the cathode stream will produce radiation in the form of electromagnetic waves or photons, this radiation being the x-rays that emerge from the tube. A few of the high-speed electrons will strike nuclei of tungsten atoms. The masses of the nuclei are so great they will not be disturbed by these impacts. All the energy of these electrons will produce x-rays. These rays will have the shortest or minimum wave-lengths that can be produced by the voltage being applied to the tube. If the applied voltage be known, the wave-lengths of these x-rays in Angström units can be determined by dividing 12,354 by the voltage in peak volts.

Other electrons may lose part of their energy by collision with atomic electrons before striking the nuclei; others may strike target electrons which in turn may hit target nuclei, and others may lose part of their energy in emitting radiation by traveling close to atomic nuclei. In these and in other ways x-rays are produced including all wave-lengths from the minimum for that voltage to those having maximum wave-lengths. The longer rays are not penetrating enough to pass through the glass wall of the x-ray tube. Those that emerge from the tube are included in what is called the general x-ray spectrum (Fig. 36). In this spectrum the greatest intensity of x-rays will be those having wave-lengths about 1.6 times the minimum produced by that particular voltage.

In the bombardment of the anode, if K-level electrons are displaced or dislodged the tungsten atoms become unstable or excited.

Under such conditions electrons from other atomic levels will plop into the places made vacant by the displaced K-electrons, their energies being used in the initiation of *x*-rays. The wave-lengths of these *x*-rays are shorter than the adjacent rays in the general spectrum. Since there are more than one level from which the replacing electrons may come, the *x*-rays will have more than one wave-length. The same phenomena may occur from displacement and replacement of L-level electrons. The *x*-rays will be longer than those of the K radiation and shorter than the adjacent rays of the general spectrum. *X*-rays coming from energy levels lower than the L series are of such long wave-lengths that they do not emerge from the *x*-ray tube. *X*-rays produced in this way are known as characteristic *x*-rays, and their addition to the general spectrum makes the complete *x*-ray spectrum.

All materials and substances emit characteristic radiation when bombarded with electrons. For each of the elements a particular tube voltage is required for each characteristic radiation and the wave-lengths of the radiation are constant. The necessary voltage is low for elements low in the periodic table and the rays have longer wave-lengths. The required voltage gradually increases for more complex elements and the wave-lengths become shorter. For tungsten the K series of characteristic *x*-rays are produced by 69.3 kilovolts and the rays have a wave-length of 0.17 A.U. Characteristic K radiation will not be emitted by tungsten unless the voltage is higher than 69.3 kilovolts. Still higher voltages will increase the intensity of the characteristic *x*-rays without changing the wave-lengths.

The speed with which the electrons are passing at the time of their sudden interruption determines the wave-lengths of the resulting Roentgen-rays. The voltage of the current through the tube provides the electrons with their velocity. Those traveling at the greatest speed, impelled by highest voltages, produce the shortest wave-lengths. Therefore the voltage of the current through the tube is a measure or a method of indicating the wave-length or quality of the rays produced.

As described above, even with a constant voltage, it is impossible to produce a beam of *x*-rays all of the same wave-length. In the transformer type of *x*-ray machine the inconstancy of the voltage is another factor in the production of heterogeneous rays. The alternating high-voltage current is partially rectified by the rectifier or the *x*-ray tube, the amount of rectification probably depending somewhat on the type of rectification and the design of the rectifier. If it be assumed that one-half of the current of a voltage of 60 kilovolts is rectified, then during each half cycle the voltage variation

extends from 30 to 60 and back to 30 kilovolts. Roentgen-rays corresponding to all these voltage variations will be produced.

In roentgenography there is no advantage in rectifying and using voltages of less than approximately 30 peak kilovolts. The Roentgen-rays produced by them would all be of long wave-lengths and not sufficiently penetrating to pass through the glass wall of the tube and the aluminum filter in their path. If the voltage of the current be increased in progressive steps from this minimum, Roentgen rays of shorter and shorter wave-lengths will be added to the resultant beam with retention of all the rays of longer lengths. Fig. 36 shows graphically the distribution of the different wave-lengths in a beam produced by a current of 70 kilovolts (Shearer).

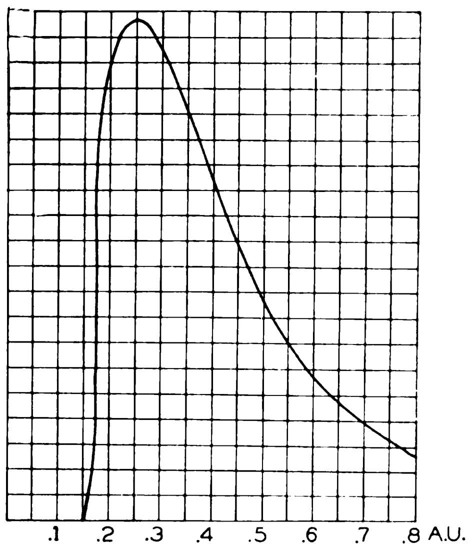

FIG. 36.—Wave-lengths produced by 70 kilovolts. (From Shearer.)

The shortest rays are 0.15 A.U. in length. These are few in number. The predominant wave-length is in the neighborhood of 0.25 A.U. The longest are over 0.8 A.U. in length. Kaye gives a table of the shortest wave-lengths produced by different voltages from 10 to 300 peak kilovolts. Within the range of voltages useful in roentgenography, these are given in Table I.

From this table if the shortest wave-length produced by 40 kilovolts (0.310) be subtracted from that produced by 30 kilovolts (0.413), the difference will be 0.103. This means that the addition of 10 kilovolts to a voltage of 30 kilovolts will decrease the shortest wave-lengths of the resultant Roentgen-rays by 0.103 A.U. If the wave-length given in the table for each voltage be subtracted from

that given for the next lower voltage, it will be found that the decrease in the wave-lengths diminishes as higher voltages are reached. For example the decrease in shortest wave-length from 80 to 90 kilovolts is but 0.017 A.U. This shows that the addition of 10 kilovolts will have much more effect on the resultant rays if the initial voltage be low than if it be high. The importance of this will be considered in a later section (see p. 129).

TABLE I.

Kilovolts (peak).	Shortest wave-lengths in A.U.
30	0.413
40	0.310
50	0.248
60	0.207
70	0.177
80	0.155
90	0.138
100	0.124
110	0.113
120	0.103

While the quality (wave-lengths) of Roentgen-rays depends on the voltage of the current sent through a tube, the amount, number, quantity or intensity of rays in a unit of time is directly proportional to the milliamperage, as measured by the milliamperemeter. Inasmuch as the current (measured in milliamperes) is carried from the cathode to the anode by electrons, the quantity of rays also depends on the number of electrons given off by the heated filament. Since the heat of the filament comes from the electric current in the filament circuit, then the quantity of rays also depends on the filament current as measured by the filament amperemeter.

From this it may be seen that the quantity of rays may be indicated in one of two ways: by the amperage in the filament circuit and by the milliamperage of the high-voltage circuit. The filament current necessary to produce a given heat and consequently a given number of electrons is not the same in all *x*-ray tubes, nor is it the same at all voltages in any one tube. For this reason the milliamperage of the high-voltage current through the tube is the satisfactory electrical indication of the quantity of the resultant rays.

There are ways in which the quality and quantity of a Roentgen-ray beam may be directly measured, but none of them is practical for ordinary purposes. All are so complicated that extra equipment and special training in physics are necessary for accurate results. For this reason they are not in common use. Therefore the quantity and quality of Roentgen-rays in most laboratories are measured and spoken of in terms of the electric current used in their production: the voltage of the current as an indicator of quality and the

milliamperage of the current with the time of the exposure as a measure of the quantity. Later it will be shown that the distance from the tube anode to the film also has a marked effect on the quantity of Roentgen-rays reaching the film.

The voltage may be spoken of as measured by a spark gap in inches or centimeters, as average or effective kilovolts, or as peak kilovolts. By multiplying one by the other, the milliamperes and the time may be combined as milliampere-seconds. Thus 20 milliamperes for five seconds would be 100 milliampere-seconds; 50 milliamperes for two seconds would be 100 milliampere-seconds; 10 milliamperes for one second would be 10 milliampere-seconds; 40 milliamperes for one-quarter second or 100 milliamperes for one-tenth second would be 10 milliampere-seconds, etc.

GENERAL PROPERTIES OF ROENTGEN-RAYS.

The usefulness of Roentgen-rays in the practice of medicine depends on a few general properties. In diagnosis these are:

1. The ability of Roentgen-rays to penetrate some objects and substances opaque to ordinary light.
2. The ability of Roentgen-rays to affect a photographic emulsion.
3. The ability of Roentgen-rays to cause fluorescence of certain crystals.

In addition, Roentgen-rays have very important biological effects upon which depend their usefulness in therapy, and they possess the power of ionizing gases, a property used in the accurate measurements of intensities of exposures used in treatments.

The Penetrating Power of Roentgen-rays.—The penetrability of a substance by Roentgen-rays depends on the nature of the substance, its thickness, and the quality of the rays attempting to pass through it. For different substances of the same thickness the penetrability is directly proportional to the density. Gases, for instance, have little resistance to the passage of Roentgen-rays through them. Aqueous liquids, being of greater density, are less easily penetrated. Still denser substances, such as the heavy metals, either in sheets or in solutions of their salts, are more opaque. A certain depth of weak solution of a salt of a metal would be less dense and therefore more penetrable than a similar depth of a stronger solution.

In addition to the density the penetrability also depends on the thickness of the substance and the quality of the rays. Rays of a particular quality may easily penetrate a certain thickness and all be absorbed by a greater thickness of the same substance. This may be illustrated by an example from medical roentgenography. Rays just penetrating enough to pass through a thin part, such as

the hand, would all be absorbed by a thicker part, such as the hip. While in thin sheets the denser metals may not be opaque to average Roentgen-rays, in thicker masses the opacity may be complete. Even this is relative, for Roentgen-rays are now being used to detect flaws and defects in thick masses of brass, steel, etc.

The penetrating power of Roentgen-rays depends on their wave-lengths—the shorter the rays the greater the penetrability. Since the wave-lengths are determined by the voltage of the current producing the rays, penetrability may be determined and expressed in terms of voltage. This makes it possible, without making an actual determination of the wave-lengths, to indicate a certain quality of rays, both in wave-lengths and in penetrability, by mentioning the voltage at which they were produced. While it is but a rough measure of quality, this is the common and usual practice in roentgenography.

The Effect of Roentgen-rays on a Photographic Emulsion.—The second important property of Roentgen-rays is their ability to affect a photographic emulsion in a manner similar to visible light. A photographic emulsion is made of a preparation of silver bromide suspended in an emulsion of gelatin and spread in a thin layer on some form of support. If on a sheet of glass, a plate is made; if on a transparent celluloid-like base, a film is the result. The most useful and most common form of photographic material for roentgenography is a film with the emulsion in layers of similar thickness on both sides of the support. This is called a double-coated film.

The film support is made of cellulose acetate in which is incorporated a small amount of bluish dye. This dye is added to offset, in a measure, the yellowish light in most viewing apparatus giving more of a white light when the films are examined. Two kinds of films with different emulsions are currently produced. On one of these the emulsion is more sensitive to the fluorescent light from intensifying screens than to the direct action of x-rays. Although these films may be used without screens, exposures with them are usually made with double intensifying screens. The other films, called non-screen films, are made with the emulsion sensitive to the direct action of the x-rays and are used for exposures without screens.

The change which takes place in a photographic emulsion when struck by light or Roentgen-rays is so slight that it cannot be seen nor measured by chemical or physical means. It does not become apparent until the emulsion is put into a reducing solution known as a developer. In this the affected silver is reduced to a metallic state in the form of black granules so minute that they are invisible to the unaided eye, and held in position by the surrounding gelatin. Unaffected silver in the emulsion remains unchanged and must be

removed. This is done by immersing the film in a second solution, known as a fixing bath or fixer, in which the unchanged silver is dissolved from the emulsion.

The processes through which it is put after exposure are collectively known as the processing of the film. When properly carried out, the result is a clear, clean, transparent film with the image on it produced by the arrangement of the minute granules of metallic silver in the gelatin.

The Fluorescent Action of Roentgen-rays.—The third important property of Roentgen-rays is their ability to cause fluorescence of certain crystals. When a substance fluoresces it gives off visible light. If caused by Roentgen-rays, the rays themselves are invisible; they are absorbed by the chemical substance and cause it to emit rays of much longer wave-lengths, wave-lengths within the range of the visible spectrum. Fluorescence of this kind from a screen of barium platinocyanide was the phenomenon that first attracted the attention of Professor Roentgen and led to the discovery of the rays which bear his name.

In 1896, from a list of 1800 materials that fluoresced when affected by Roentgen-rays, Edison selected calcium tungstate as the most suitable for fluorescent screens. Later it was found that cadmium tungstate, emitting more of a greenish or yellowish fluorescence, was more suitable for fluoroscopic screens. Calcium tungstate, emitting light more toward the violet and near ultraviolet portion of the spectrum, is still used as the fluorescent material in intensifying screens. A new preparation of zinc sulphide recently has been introduced as another material for both fluoroscopic and intensifying screens of increased brilliancy and speed.

In the manufacture of screens, crystals of the fluorescent substance are carefully purified, finely ground, incorporated in some binding substance, and spread in a layer of uniform thickness on cardboard or other support. The fluoroscopic screen is covered with a piece of lead glass and mounted in a frame. Fluorescence of the screen can be seen through the glass, but the Roentgen-rays causing the fluorescence are stopped by it.

An intensifying screen is made to be placed in intimate contact with a photographic emulsion during an exposure. When this is done, the effect on the emulsion is twofold: that of the Roentgen-rays which reach the emulsion, and that of the fluorescence from the screen. In this way a smaller quantity of rays is required to produce a certain effect on the emulsion than if the screen had not been used.

To further reduce the quantity of rays necessary to produce a certain photographic effect on a film, use is made of double-coated

films and double intensifying screens. The screens are mounted with their fluorescent surfaces facing each other in an apparatus known as a cassette. If a double-coated film be placed in a cassette and the cover closed, the screens will be in intimate contact with the emulsion on the film. When exposed, the effect of the Roentgen-rays is not more than an eighth of the total, the greater part being caused by the fluorescence of the screens. The emulsion on present-day *x*-ray films is particularly sensitive to the fluorescent light from intensifying screens. It may be said, therefore, that, within the range of voltages used in roentgenographic work, the Roentgen-rays are used to excite fluorescence of the screens and that it is the emission from them that produces the effect on the films.

INTENSIFYING SCREENS.

Double intensifying screens of good quality, properly mounted in suitable cassettes, are a very important part of a modern *x*-ray equipment. Quality in screens includes freedom from grain and afterglow and uniformity in speed. Graininess is caused by large crystals of the fluorescent salt in the screens. Afterglow means a continuation of the fluorescence after an exposure has stopped. If it continues for a sufficient time, it may be enough to cause an image on an unexposed film placed in a cassette immediately after an exposed film has been removed. Screens of uniform speed are such that different ones will give the same photographic effect with the same exposure. Modern manufacturing methods largely have eliminated grain, afterglow, and irregularities in speed from intensifying screens.

Intensifying screens are often sold in pairs. One of these is thinner than the other. It is to be mounted in the front of the cassette. It is made thin so as to absorb as little as possible of the Roentgen-rays passing through its back to reach its fluorescent surface, the film, and the other screen.

The initial mounting of intensifying screens in cassettes should be done with considerable care. To hold the screens in place, thin adhesive tape, special rubber cement, or special paste should be used. Water-soluble glue should never be used, for it will penetrate the backs of the screens and make a hard, inflexible spot on the fluorescent surfaces. Only a good quality of wool felt free from foreign material, wool fat, and oil should be used as padding.

Cassettes should be constructed and the screens mounted in them in such a way that there will be absolute contact between the screens and the emulsion of the films over their entire surfaces. If contact between screens and films be imperfect, the fluorescence

from the screens will not be limited in its action on the emulsion to an area of the same size as the one from which it originates, but will cover a larger area. Images on films exposed in cassettes with poor contact have a blurred appearance which may be spread over the entire film or limited to one or more smaller areas. If films have such an appearance and movements during exposures can be excluded, poor contact between screens and films should be suspected.

Imperfect contact between screens and films is a rather common cause of poor quality in x-ray films. To test cassettes for contact, secure a piece of wire meshing, with meshes from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, large enough to cover the largest size of cassette. Lay the wire on the cassette and expose a film through it. Sixty kilovolts, 30 milliamperes for one-half second, at a 35-inch distance, is a satisfactory exposure. When a film so exposed has been developed, if the image of the wire be distinct over the whole film, the contact between film and screens is good. If there be blurring of the images of the wire in any part of the film, contact at that place is poor and should be corrected (Fig. 37).

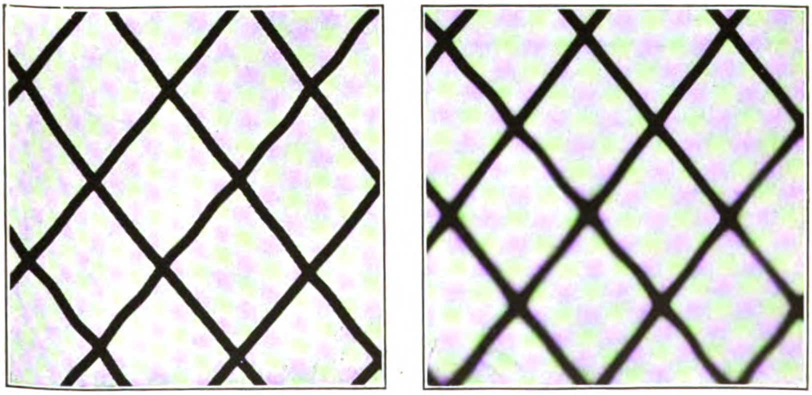

FIG 37.—The image of a wire screen showing good and poor contact of intensifying screens and film. (Eastman Kodak Company.)

This can be done by building up with paper the areas where contact is deficient. Cut out a series of pieces of paper, diminishing in size from a large piece that covers the whole area of poor contact to a small one, all of approximately the same shape. Fasten these together with glue or paste (Fig. 38). When finished, place this under the screen on the lid of the cassette next to the felt pad. This will build up the low area and restore contact.

Cassettes may be dropped or subjected to other rough handling sufficient to change their shape and the contact of the screens. For

this reason they should be tested periodically and the defects corrected. This is particularly important in mounting new screens in used cassettes.

The useful life of intensifying screens depends largely on the care they receive. The fluorescent surfaces should be protected as much as possible. They should never be touched with the fingers nor exposed to dust or other foreign material. In placing films in cassettes, the black papers should be removed and the films dropped gently into place. Sliding the film across the screen not only tends to cause static electrical marks and scratches on the films, but it will abrade the screen surfaces. A good procedure in removing films from cassettes is shown in Fig. 39.

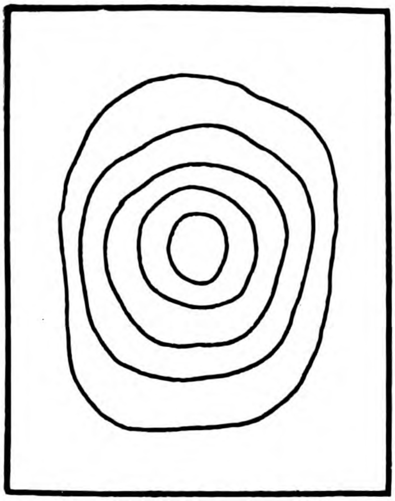

Fig. 38.—Showing a method of making paper pads for building up places of poor contact in intensifying screens and cassettes. (Eastman Kodak Company.)

Organic material such as finger prints, lint from felt padding, etc., may be removed from screens by dusting with a camel's hair brush or a silk duster and by washing with cotton and Ivory soap, drying with a soft cloth. Carbon tetrachloride may be used in cleaning; alcohol and hydrogen peroxide should never be used. Metallic particles from cassettes and developing hangers may become imbedded

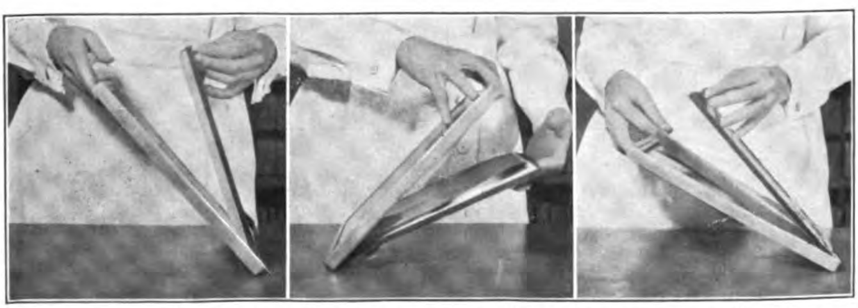

Fig. 39.—The proper method of removing a film from a cassette. The lid of the cassette is opened; the cassette is inverted with the lid beneath and the film permitted to drop against the lid; when the cassette is again turned with the lid up, the film is permitted to drop between the thumb and index finger; it is grasped and removed.

in the screens and even after removal leave minute permanent defects. Developing solutions do no damage if washed off immediately; if permitted to dry they leave permanent splotches. Defects in screen surfaces produce spots on all films afterward exposed with them. False images on films caused by screen defects sometimes make film interpretation difficult. When defects in screens become so numerous as seriously to reduce the quality of the films exposed with them, the screens should be replaced.

The intensifying or intensification factor of intensifying screens is defined as the ratio of the exposure required to produce an image of given density with the use of screens to that required to produce a similar image without the use of screens. This factor with a given pair of screens increases with increases in tube voltage and increases with greater thicknesses of absorbing medium. Anode-film distance and tube current in milliamperes have little effect on the intensifying factor.

There is a great deal of difference in the intensifying factor of different kinds of screens. In general, screens can be divided into three classes. "High-definition" or "detail" screens are made with finely divided or ground crystals of fluorescent material. They are made to be used when maximum detail is desired, but their intensifying factor is low. Just the opposite are the "speed" or "high-speed" screens. The crystals are larger, the fluorescent action is greater, and they are much faster, with a high intensifying factor. Because of the larger size of the crystals there is more grain on the films and definition is diminished. "Par" or medium speed screens are a compromise between the fastest and the slowest, having some of the speed of the first and some of the detail of the second. To these may be added a fourth, or "Fluorazure," screen which is the fastest of all, but with the poorest detail on the films exposed with them.

In mounting and caring for intensifying screens, it always is best to follow the instructions of the manufacturers.

ROENTGENOGRAPHIC PHENOMENA.

Roentgenography depends on the penetrating power of Roentgen-rays, their ability to affect a photographic emulsion, and their ability to cause fluorescence in crystals. A consideration of the phenomena which take place when a film of a part of the body is exposed will illustrate the manner in which use is made of these properties. It must be assumed that a voltage has been selected that will give rays of the proper quality. A cassette, loaded with double intensifying screens and a double-coated film, is placed under the part of the body, the tube is centered, and the exposure made.

The beam of Roentgen-rays leaving the tube is composed of all wave-lengths from those just penetrating enough to pass through the glass wall of the bulb and the filter to the shortest that can be produced by that particular voltage. Although consisting of different wave-lengths, experience has taught that the proper quality and quantity of rays are present to give a satisfactory film of that particular part.

Undoubtedly many of the rays will be absorbed or stopped by the superficial layers of tissue, this absorption increasing as the rays penetrate deeper and deeper. It will not be uniform, for the denser portions, such as bone, will absorb a greater proportion of the rays than other tissues. Even the absorption by bone is irregular, denser parts, such as the cortex and trabeculæ, absorbing more than the marrow cavity and the intertrabecular spaces. Those portions of the part around the bone, not being so dense, will not stop so many of the rays. Even here again the absorption will not be uniform, for there are some differences in density in the soft tissues. Muscle masses, tendons, heavy ligaments, etc., are denser than layers of fat and superficial tissues.

Only those rays that reach the intensifying screens and the emulsion of the film will produce an effect on the silver salts, partly through direct action, but mostly through fluorescence of the screens. Since the absorption or stoppage of rays is irregular, the effects of those which pass through are also irregular. Because fewer rays penetrate the denser portions, the fluorescence and direct action will be less under these parts than elsewhere, less of the silver in the emulsion will be affected, so that on the finished film the shadows of these portions will appear the lightest. Images of structures of less density will vary through all gradations from light gray to black. Should the film be larger than the part being examined, the blackest portion will be at the margins where there is nothing to interfere with the rays.

In the preceding paragraphs it has been assumed that in making a roentgenogram all of the rays were either absorbed or passed through the tissues in a direct line. This is not exactly true. Whenever an *x*-ray beam strikes any sort of matter, some of the rays pass directly through, the emerging rays having the same wave-lengths as the incident rays. The remainder interact with the substance in various ways. Some of them are scattered without change, some are absorbed, some produce characteristic rays, and some lose part of their energy and produce *x*-rays of longer wave-lengths. Absorption is divided into two kinds, apparent and true absorption. Suppose the *x*-rays (photons) interact with the nuclei of the atoms, or with electrons attracted to the atoms with more energy than the

x-rays possess. These will not lose energy, but they will be deflected, still having the same wave-lengths as before the impacts. These deflections occur in all directions, but mostly in the general direction of the primary beam; scattered radiation is produced. This is spoken of as unmodified scattering because the wave-lengths of the *x*-rays have not been changed. It is also classed as apparent absorption, for the rays are not actually absorbed, but are deflected from the direct path through the substance.

X-rays have the same power to produce characteristic radiation as do high-velocity electrons. If the wave-length of the primary beam be short enough, the *x*-rays may have sufficient energy to eject electrons from the various energy levels (K, L, M, etc.) of the atoms of the substance (see pp. 10 and 77). Replacement of these electrons from other energy levels produces characteristic *x*-rays and the electrons become photoelectrons. These photoelectrons have sufficient energy to produce ionization by collision with atoms along their paths. This production of characteristic radiation and photoelectrons is called true absorption, for the energy of the primary beam is utilized in producing these effects. Characteristic *x*-rays are emitted in all directions and form another component of scattered *x*-rays.

Characteristic *x*-rays produced by the passage of an *x*-ray beam are the same as those emitted when different substances are bombarded with electrons, except that their method of origin is different. Low energy *x*-rays (longer wave-lengths) produce characteristic rays from the simpler atoms. As the complexity of atoms increases, higher energy *x*-rays are necessary to produce characteristic rays. Since the atoms that make up the tissues of the body, like carbon, hydrogen, oxygen, nitrogen, etc., are all less complex atoms, the energy of nearly all beams of *x*-rays used in radiography is sufficient to excite characteristic radiation from them. This is one of the reasons for pronounced scattering in animal matter (Kaye).

Modified or Compton scattering, in which the wave-lengths as well as the direction of the *x*-rays are altered, results from the impact of the rays with electrons in the lower energy levels of atoms, those not closely attached to the nuclei. When this occurs, the energy is utilized in sending the electrons off at various angles as recoil electrons, and in producing *x*-rays of less energy (longer wave-lengths). The energy of the primary *x*-rays and the amount transmitted to the electrons determine the wave-lengths of the secondary rays and the direction of their scattering. These scattered *x*-rays are emitted in all directions.

The phenomena of scattering and absorption, particularly the production of photoelectrons and the production of longer wave-

length x-rays and recoil electrons through the Compton effect, cannot be explained by the electromagnetic wave theory. These are the phenomena that must be explained by the theory that x-rays are bundles of energy called photons, the amount of energy being expressed in quanta (see p. 74).

From this discussion it is apparent that scattered x-rays consist of: (1) x-rays that have been deflected from their paths but have not been otherwise altered, (2) characteristic x-rays, depending on the atomic structures of the substance through which the primary beam is passing, and (3) x-rays of longer wave-lengths than those of the primary beam. All of these scattered x-rays produce an effect if they strike a photographic emulsion, and they are able to excite fluorescence in intensifying screens. When scattering is marked in roentgenographic exposures, the density of the films is increased and detail and contrast are materially diminished.

In roentgenograms of thin parts, scattering interferes but little with the quality of the films. When thick parts are exposed, however, as for example a thick abdomen, scattering is quite marked. The bad effects of scattered radiation may be reduced by using a small cone or diaphragm and including only a small portion of the body on each film, or a device may be used for absorbing the scattered radiation. Potter-Bucky diaphragms and stationary or wafer grids are apparatus used for this purpose.

POTTER-BUCKY DIAPHRAGM.

Reduced to its essential parts, a Potter-Bucky diaphragm consists of a grid with some form of mechanism for moving it between the patient and film while an exposure is being made. The grid is made up of alternating parallel thin lead strips separated by strips of soft wood or some similar material. The grid ratio is the thickness of the grid divided by the distance between the lead strips, or the ratio of the height to the width of the slots between the lead strips. Older forms of grids are $\frac{5}{16}$ inch thick with the spaces $\frac{1}{16}$ inch apart. The ratio of a grid of this kind is 5 to 1. Grids of more recent manufacture are chiefly of two kinds. Both have 50 lead strips to the inch. One is $\frac{6}{50}$ inch thick with the strips $\frac{1}{50}$ inch apart, giving a ratio of 6 to 1. The other is $\frac{8}{50}$ inch thick with similar spacing and a ratio of 8 to 1.

The earlier Potter-Bucky diaphragm grids were curved, the curvature forming part of the arc of a circle, the radius of which was 25, 30, or more inches, depending on the distance from the anode of the tube to the grid when the diaphragm is used. The inclination of the lead strips was such that the planes of all of them would con-

verge in a line through the focal spot of the tube. The excursion of a curved grid was not restricted, for the grid was always in the arc of a circle of which the tube anode is the center.

Curved-top Potter-Bucky diaphragms were not entirely satisfactory. The posing of patients for many examinations was difficult. Except near the center of the diaphragm, there was considerable distance from the patient to the film, increasing distortion. Also, curved-top diaphragms were difficult to combine with other apparatus. For these reasons diaphragms with flat grids were developed. In these the lead strips in the grid are inclined so that their planes intersect at the anode of the tube when the tube is centered over the grid. The alignment of the grid is correct in only one position. The excursion of the grid during an exposure must be short, usually limited to 1 or 2 inches.

The grid of a Potter-Bucky diaphragm is provided with a mechanism for moving it at a uniform rate of speed between the patient and the film during an *x*-ray exposure. Provision is made for adjusting the speed of the grid travel to conform to the length of the exposure. In the older grids the speed could be varied from half a second to twenty seconds or more. In newer forms the grid speed is such that exposures as short as a thirtieth or a twentieth of a second are permissible, and they may be prolonged as much as ten or more seconds.

The top of a Potter-Bucky diaphragm is curved or flat depending on the grid, and is made of some material relatively nonopaque to Roentgen-rays but strong enough to support the weight of the patient. Most often aluminum or thin wood is used. When installed in a table, the grid operates under the table top. Sliding in and out beneath the grid is a pan or tray in which the films and cassettes are placed. To minimize distortion, the grid should be as near the top as possible without there being any interference with the movements of the grid. Also, the film should be as near the under surface of the grid as it can be placed without interference with grid motion.

When a Potter-Bucky diaphragm is used, the anode of the tube should be placed exactly above the center of the grid at the proper distance. When so placed the direct rays from the tube will pass through the openings between the lead strips. Some variation in the distance of the tube from the grid is permissible, and at times it may even be an advantage to increase the anode-grid distance over that usually employed. The tube may be centered with reference to the strips in a longitudinal direction either way, but a lateral position much out of this line is not permissible. Grids with a ratio of 6 to 1 permit a lateral shift of the tube enough to expose

stereoscopic films. In using grids of 8 to 1 ratio, exact centering both in height and in lateral shift is much more critical; thus very little off-centering is permissible.

The usefulness of the Potter-Bucky diaphragm depends on the fact that those rays which are scattered during an x-ray exposure and which attempt to emerge at an angle with the direct rays from the tube, strike the lead strips of the grid and are stopped (Fig. 40). By its use as much as 90 per cent of the scattered radiation is absorbed, the photographic effect on films so exposed being pro-

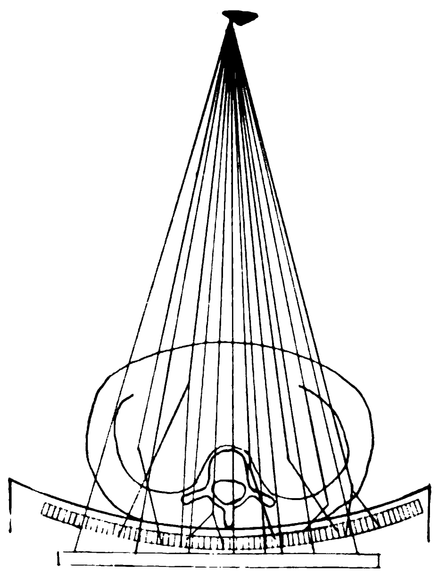

FIG. 40.—Diagram illustrating the absorption of scattered Roentgen-rays by the lead strips of the grid of a Potter-Bucky diaphragm.

duced almost entirely by rays that have passed directly through the part being examined. The elimination of scattered radiation in this way markedly improves detail and contrast on the finished films. For this reason this apparatus is indispensable in making films of thick portions of the body necessitating penetrating rays produced by a relatively high voltage.

In using a Potter-Bucky diaphragm the tube must be over its center. If the diaphragm be separate from the rest of the equipment, the tube must be localized before the patient is put in place. On many tables equipped with diaphragms, appropriate markings on the arm of the tube stand supporting the tube and on the rail of the tube stand exactly place the tube anode over the diaphragm center. The film and patient are then placed with proper relation-

ship to each other. When all is ready, the grid must be set in motion before the exposure starts and must continue moving until after the exposure has stopped. If this be not carefully observed or if the movement of the grid be not steady and uniform, the images of the lead grid strips will be present on the film. In some equipments provision is made for closing and opening the magnetic *x*-ray switch or contactor by the diaphragm grid during its excursion.

The improper use of a Potter-Bucky diaphragm will result in the shadows of the lead strips of the grid on the films. The grid must be in steady, uniform motion during the exposure. If the movement of the grid does not begin until after the exposure has started, if the exposure continues after the grid has stopped, or if the movement of the grid is irregular, grid marks will show on the films. Irregular surges in the high-voltage current may cause grid lines on the films. The movement of the grid may be too slow for short exposures. Another cause for grid shadows on films is synchronism between the motion of the grid strips and the pulsations in the tube current. With full-wave rectified apparatus using 60-cycle alternating current, the *x*-rays are produced by the pulsations in the current, there being 120 such pulsations a second, 1 for each half cycle. In self-rectified or half-wave rectification there will be 60 pulsations a second. If the speed of the grid is such that succeeding flashes of *x*-rays directly strike succeeding grid strips, synchronism exists and grid marks will show on the films. To prevent synchronism, obviously exposures must be longer with 60 than with 120 a second.

The elimination of grid lines from films exposed with a Potter-Bucky diaphragm depends on their cause. If the lines be due to exposures that are started before the grid begins to move, or that continue after the grid has stopped, the necessary correction is obvious—start and complete the exposure while the grid is in motion. If the lines be due to an irregular movement of the grid, mechanical adjustment to restore steady motion is necessary. If the exposure be too short for the grid speed, it must be lengthened. If irregular surges be the cause of the grid lines, the surges must be stopped before the grid lines can be eliminated.

By proper calibration it may be possible to locate synchronizing positions on the diaphragm timer apparatus or on the speed control of the grid. By the use of other positions grid lines from synchronization may be avoided. If certain exposures result in grid lines, either by slightly increasing or by decreasing the exposure time or the grid speed, the lines may be eliminated. For example, if grid lines are produced with the grid timer set at the half-second mark, an exposure of slightly more or slightly less than a half second may eliminate them. Synchronization does not occur with longer ex-

posures, and it may be necessary to lengthen the exposure to three-fourths of a second or even to a full second or more to eliminate grid lines from the films.

Some manufacturers are now producing apparatus calibrated at the factory to avoid synchronous timing; and a grid-line eliminator, a condenser apparatus that smooths out the pulsations in the alternating current, has been developed. With a grid-line eliminator, diaphragm exposures may be as short as one-thirtieth second without grid marks on the films.

In addition to cost, at first the Potter-Bucky diaphragms were objectionable because they were extra pieces of apparatus that had to be moved on and off the *x*-ray table for each exposure; because the absorption of the grid strips necessitated heavier exposures, and because the separation of the patient from the film by the grid and the top of the diaphragm increased distortion. These objections largely have been overcome by combining the diaphragms with other radiographic and fluoroscopic apparatus, by making thinner grids; and by the development of more powerful apparatus, tubes with higher ratings, and faster films and intensifying screens. Film quality is improved so much by the use of a Potter-Bucky diaphragm that an *x*-ray equipment for general purpose diagnostic work is incomplete without one.

WAFER OR STATIONARY GRIDS.

Stationary or wafer grids are designed to absorb scattered radiation. They are made of very fine strips of lead incorporated in a nonopaque binding material. When used they are placed directly on the film or cassette during an exposure. They do not increase distortion as does a Potter-Bucky diaphragm. Because they are easily portable and are stationary during exposures, they can be used for bedside and operating room work, and for very short exposures. However, the fine lead strips are all shown on the films. When closely viewed the appearance is objectionable; but when seen at the normal viewing distance, the individual lines are imperceptible. Scattered radiation is satisfactorily removed.

The Liebel-Flarsheim stationary grids have 50 or more lead strips to the inch. They have a ratio of approximately 5 to 1. Some of the larger ones are aligned or focused like the grid of a movable diaphragm with a focal distance of 36 inches. They are said to be 88 per cent efficient in removing scattered radiation. The Lysholm grid, formerly imported from Sweden, has strips 0.04 millimeter thick and 2 millimeters wide, spaced 0.4 millimeter apart.

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CHAPTER V.

DARK-ROOM EQUIPMENT AND TECHNIQUE.

In making roentgenograms there are two separate and distinct processes. One of these is the exposure of the films in the x-ray laboratory; the other is the processing of the films in the dark room. Correct exposures and proper processing are both necessary for satisfactory films. Too often attempts are made to remedy incorrect exposures by dark-room manipulation—underdevelopment for overexposed films and forced development for underexposed films. Incorrect exposures can be detected by proper processing and the exposures corrected. Incorrect exposures may be due to ignorance; improper processing most often is due to carelessness.

A dark room need not be large. If suitable ventilation can be provided, a dark room 6 by 8 feet in dimensions may be furnished to provide adequate facilities for a small x-ray laboratory. A dark room adjacent to the x-ray room, equipped with a light lock in the entrance for ingress and egress at will, with lead protection in the wall between the two rooms, and with a pass box in the wall for exposed and unexposed films, is the most convenient type of arrangement. Companies selling x-ray films and x-ray equipment will furnish dark-room plans on request.

The lighting and ventilation of a dark room are both important. When undeveloped films are being handled, all daylight and other outside light must be excluded. Illumination with red or green dark-room lights while films are being processed usually is safe. The electric bulbs in the fixtures must not exceed the wattage recommended by the manufacturers. By remaining in the room until the pupils of the eyes are well dilated and then looking around the doors, windows, etc., outside light leaks may be detected. The safety of the dark-room lights may be tested by taking a small film, covering part of it with black paper or some other opaque material, exposing it to the lights for two or three minutes, and then developing it for full time. If the uncovered part is fogged, the lights are not safe.

For ventilation there should be at least one outside window that can be opened when the dark room is not in use, or a ventilating fan with an adequate light lock may be installed. The window may be covered with an opaque shade, or an inside light-tight shutter may be installed. Light-tight ventilating windows especially for dark-room use have been manufactured. Painting the glass in a

window frame is unsatisfactory, for usually the paint will crack and peel off. It may be possible to cover the panes with opaque material like a thin building or composition board and exclude all the outside light.

A dark room should be kept clean. It should not be used as a storage room, nor should it be littered with discarded films, waste paper, etc. It is almost impossible to keep intensifying screens in good condition in a dirty dark room, especially when the ordinary dusts are mixed with those from chemicals that have been spilled and permitted to dry.

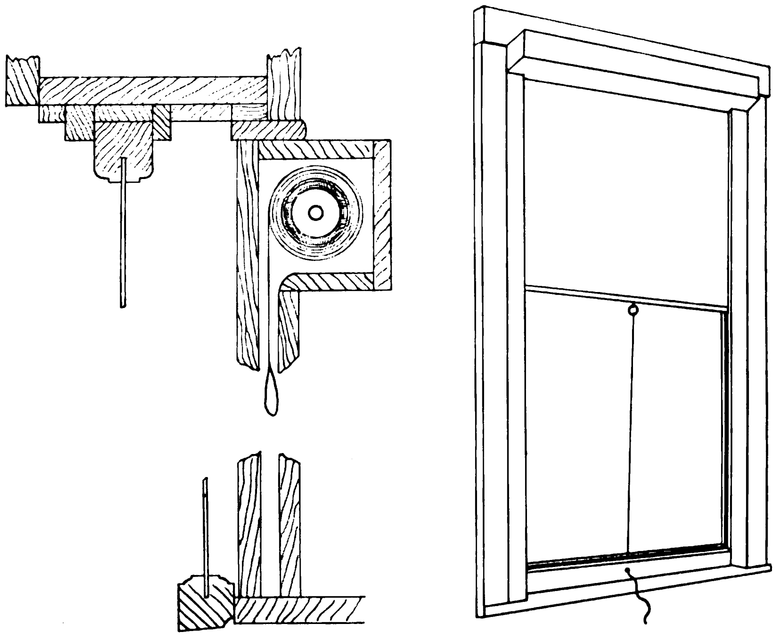


FIG. 41.—Details of the construction of a light-proof shade for dark room or x-ray room windows. The framework is made of thin boards, the curtain of automobile top material.

The dark-room equipment should include a developing tank, benches for loading and unloading cassettes and exposure holders, a rack or drier for drying films, a lead-covered box or safe for storing unused films, and a suitable assortment of film developing hangers, etc. Tray development is apt to be mussy; the solutions must be discarded after they have been used; it is difficult to maintain a proper temperature of the solutions, and it is much more complicated than tank development. If a physician has enough x-ray work to warrant investment in an x-ray equipment, a developing tank should be part of it.

Developing tanks for x-ray films have been made of several different materials and in many forms. Perhaps the best is a plastic composition material that resists the action of the chemicals in the developing solutions and is strong enough to hold its shape and not be easily broken. A tank of this kind incorporated in a suitable framework that includes 2 or 3 inches of insulating material and a closely fitting top is most satisfactory. The number and arrangement of the compartments in the tank should depend on the number of films to be developed each day. Two compartments, one for developer and one for fixing bath, with adequate space for rinsing and washing, are the minimum. The washing compartment should be provided with running water and a sewer connection.

In many places provision must be made for the control of the temperature of the processing solutions. In localities where the solutions must be cooled in hot weather, filling the tank with fresh water each day and cooling it to the desired temperature with ice will suffice for a few films. For a larger volume of work, connecting the tank with a supply of cool running water is essential. Electrical refrigerating units especially designed for developing tanks have been perfected and are a necessity in warm climates in laboratories handling a large number of films each day, if no other source of cool running water is available. In localities where cooling the solutions in the summer and warming them in the colder months is necessary a hot water connection is required. Mixing valves that provide water of the proper temperature from hot and cold water connections are a valuable adjunct to any developing tank.

In the dark room the loading bench should be removed as far as possible from the developing tank. Splashing of developing or fixing solution on unexposed films will cause defects when they are used. Developer or fixing bath on an intensifying screen, if permitted to dry, will leave a permanent stain that will cause a spot on all films exposed by it.

A suitable drying rack may be made of a piece of 2- by 4-inch studding, with $\frac{3}{8}$-inch holes slanting downward in one edge. It may be fastened to the wall or supported by a simple framework. The films are suspended by sticking one end of the cross-bars of the developing holders into the holes. To prevent frilling of the emulsion in a hot, moist atmosphere, and to hasten drying, a current of air from an electric fan often is necessary. Special film driers provided with a heating unit and an electric fan may be purchased.

A lead-lined box or a lead-covered film safe for storing unused films is an essential. A film safe with a compartment for each size of film, preferably for the 6-dozen boxes, provided with a lightproof cover, from which the films may be taken without removing and

replacing the lids of the boxes, is a time-saving apparatus. This can be made by any carpenter. The ones on the market are rather expensive and do not make provision for $6\frac{1}{2}$- by $8\frac{1}{2}$-inch films.

Suitable hooks or supports for the developing hangers, a large box for scrap paper and other trash, a sink for washing the hands, and other simple pieces of equipment, add to the ease with which dark-room work may be done and assist in keeping the room clean.

Fig. 42.—A satisfactory arrangement of dark-room equipment including a developing tank, loading bench, film drying rack, film safe, and an assortment of developing hangers. The sink is not shown in the photograph.

PROCESSING OF X-RAY FILMS.

When an x-ray film is exposed, some unexplainable change takes place in the silver halides in the emulsion. The nature of this change is unknown. It is said that a "latent image" is formed in the emulsion. When an exposed film is placed in a solution known as a developing solution or developer, the chemicals change the silver of the latent image to metallic granules or particles held in place by the gelatin of the emulsion. The silver that is not affected by the x-ray exposure remains unchanged. It is removed by placing the film in a second solution known as a fixing bath. In this the unaffected silver is dissolved from the film. Washing of the films to remove the fixing-bath chemicals and drying them to remove the water complete the processing.

Changing the silver halides to a metallic state is a reducing reaction. In the developer there are reducing agents, usually elon

and hydrochinone, or similar chemicals, that are the active ingredients. Included in the solution is sodium sulphite. This has an affinity for oxygen, and it acts as a preservative of the developer, preventing too rapid oxidation and deterioration. Potassium bromide is included as a restrainer. It acts to delay the developing action and probably prevents reduction of the unaffected silver. The action of the developer takes place in an alkaline medium. For this reason sodium carbonate or some other alkali is an essential part of the developing solution.

Sodium thiosulphate, commonly known as sodium hyposulphite or hypo, in the fixing solution changes the unaffected silver of the emulsion into a form that is readily soluble in water. Included in the fixing solution are an acid to stop the action of the developing chemicals and a chemical, usually some form of alum such as potassium chromic alum, to harden the gelatin and prevent it from swelling and frilling in the subsequent washing process. Sodium sulphite is added as a preservative.

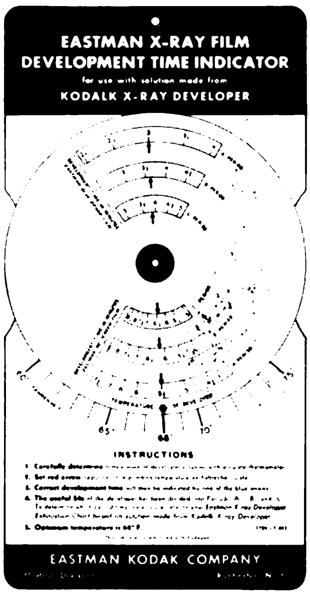


Fig. 43.—Film development time indicator. (Eastman Kodak Company.)

For the development of x-ray films the developer and fixing bath powders and solutions prepared and recommended by the manufacturers of roentgenographic supplies are advised. When made into solutions by following the directions accompanying the packages, chemicals of the proper purity and strength will be present. Such materials are slightly more expensive than chemicals that are purchased separately, but the ease and rapidity with which the solutions may be prepared more than offset the slight additional expense. Developing solutions should be made with distilled or clean rain water; tap or well water may be used for the fixing bath.

The change which takes place in the silver salts of a photographic emulsion in a developing solution, by which the silver is reduced to a metallic state, is a chemical reaction. Similar to all chemical reactions, it depends on the temperature, the time the different chemicals are permitted to act on each other, and on the strength of the solution. All of this has been carefully taken into account by the manu-

facturers of the films. The proper strength of the developing solutions, the time, and the temperature which will give the best films have been carefully determined. Deviations from recommended procedures will detract from the results and should not be practiced.

The manufacturers have determined that a properly exposed film will develop to its optimum in a certain time at a particular temperature. This varies with different films and different solutions. Formerly five minutes at 65° F. (18° C.) in fresh developer was recommended. With certain chemicals and films this is still the established practice. With other films and chemicals the time varies from three to seven minutes, and there has been a movement to establish 68° F. (20° C.) as the optimum temperature for the processing of sensitized materials. The shorter developing time is used for films exposed with screens; the longer time for non-screen films.

If the temperature of the solution be colder or warmer than that recommended, the time must be changed to correspond. Cooling of the solution slows the reaction; warming hastens it. Sixty and 75° F. (15.5° to 24° C.) are the extreme limits at which development may be carried out. Developing at a temperature that is too high, 75° F. (24° C.) or above, will reduce some of the unaffected silver in the emulsion, causing what is known as chemical fog. It also will cause a softening of the gelatin of the emulsion, producing a rough, uneven appearance known as frilling; or will loosen it from the base. A low temperature retards all chemical reactions, and if low enough will completely stop the action of some of the developing chemicals. It is for these reasons that provisions for maintaining the proper temperature of the developing solutions is so important that they should be incorporated in the dark-room equipment at the time of its installation.

The manufacturers of *x*-ray films have perfected substitute methods of developing under hot weather conditions. These are not recommended except as a last resort, when cooling of the solutions by the use of ice, electrical refrigeration, etc., have failed or are not possible. The details of these methods may be obtained from the literature of the different companies.

Time of development is just as important as temperature. If the time be too short, the films will be pale, lacking in contrast and detail. If the time be too long, chemical fog will ensue.

In developing films the only proper practice is to immerse them in the developer for a time which is regulated by the temperature and strength of the solution. The temperature may be determined at any time from a thermometer kept suspended in one corner of the developing compartment of the tank. A clock that may be set

to ring an alarm after a certain number of minutes is very convenient for timing. If an exposure has been properly made, the film may be suspended in the tank, the tank covered with a lightproof lid, and some other work done until the alarm indicates that development is complete. When done in this way development is reduced to a routine procedure which not only insures the best quality of properly exposed films, but also brings out all defects in exposure so that they may be corrected.

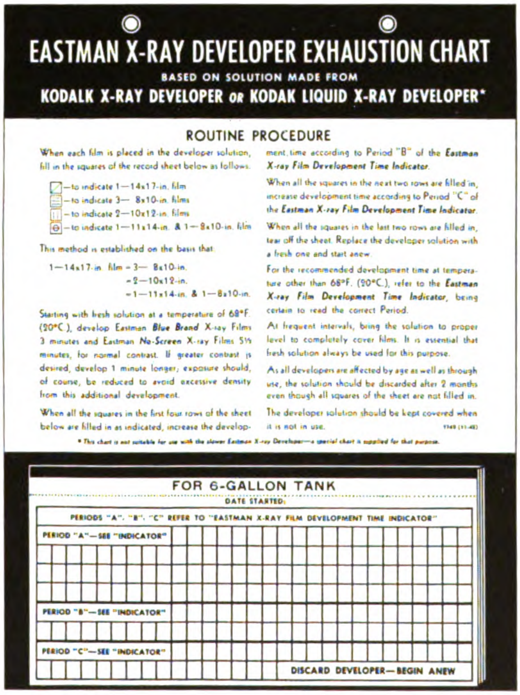
As a developing solution is used, there is a gradual decrease in the quantity of useful chemicals remaining in it. The amount of reduction in strength depends on the number of films that have been developed, and on the care that has been exercised to prevent deterioration and contamination of the solution. If exposed to the air, oxidation of the chemicals gradually takes place. This can be retarded by keeping the developer covered when not in use and prevented by a float that rests on the top of the solution. A thin board, of the proper size, that has been soaked in hot paraffin, makes a good float.

Fixing bath is the chief source of contamination of a developing solution. This may be allowed to drip into the developing compartment of the tank when examining films as soon as fixation is complete, or it may be carried in on developing hangers. A dark-room light used for viewing films after fixation should never be over the developing compartment of the tank. In washing films care should be exercised to remove all of the fixing bath from the hangers. If this be not done, the solution will dry and be carried into the developer with the next films.

A reduction in the strength of the developer from exhaustion requires an increase in the time of development. A method of time-temperature tank developing has been perfected based on a tank developing system chart (Fig. 44). On this chart provision is made for keeping a record of the number of films developed in each tank of solution. When a certain number is reached, developing time is increased by one minute. After more films are developed, the time is increased for an additional minute. An additional number of films exhausts the solution and it is discarded. The chart includes time corrections for variations in the temperature of the solutions. Donaldson has developed an ingenious "chip-in" method of keeping count of the number of developed films by the use of poker chips of different colors. In either method the level of the solution in the tank is kept constant by the addition of fresh developer.

In an alternate method of tank development the original strength of the solution is maintained and the life of the developer is prolonged by the use of a replenisher. In this method the films are

taken from the developer without permitting the solution removed with the films to drain back into the tank. Replenisher, which usually is full-strength fresh developer, is added from time to time to maintain the level of the solution in the tank. This is usually 3 ounces for each 14- by 17-inch film or equivalent. The developer is used until the total amount of replenisher that has been used equals four times the original volume of solution, or at most for three months.



EASTMAN X-RAY DEVELOPER EXHAUSTION CHART

BASED ON SOLUTION MADE FROM

KODALK X-RAY DEVELOPER OR KODAK LIQUID X-RAY DEVELOPER*

ROUTINE PROCEDURE

When each film is placed in the developer solution, fill in the squares of the record sheet below as follows.

—to indicate 1—14x17-in. film
—to indicate 3— 8x10-in. films
—to indicate 2—10x12-in. films
—to indicate 1—11x14-in. & 1—8x10-in. film

This method is established on the basis that:

1—14x17-in. film = 3— 8x10-in.
= 2—10x12-in.
= 1—11x14-in. & 1—8x10-in.

Starting with fresh solution at a temperature of 68°F. (20°C.), develop Eastman *Blue Brand* X-ray Films 3 minutes and Eastman *No-Screen* X-ray Films 5½ minutes, for normal contrast. If greater contrast is desired, develop 1 minute longer; exposure should, of course, be reduced to avoid excessive density from this additional development.

When all the squares in the first four rows of the sheet below are filled in as indicated, increase the development time according to Period "B" of the *Eastman X-ray Film Development Time Indicator*.

When all the squares in the next two rows are filled in, increase development time according to Period "C" of the *Eastman X-ray Film Development Time Indicator*.

When all the squares in the last two rows are filled in, tear off the sheet. Replace the developer solution with a fresh one and start anew.

For the recommended development time at temperature other than 68°F. (20°C.), refer to the *Eastman X-ray Film Development Time Indicator*, being certain to read the correct Period.

At frequent intervals, bring the solution to proper level to completely cover films. It is essential that fresh solution always be used for this purpose.

As all developers are affected by age as well as through use, the solution should be discarded after 2 months even though all squares of the sheet are not filled in.

The developer solution should be kept covered when it is not in use.

* *This chart is not suitable for use with the slower Eastman X-ray Developer—a special chart is supplied for that purpose.*

FOR 6-GALLON TANK

DATE STARTED:

PERIODS "A", "B", "C" REFER TO "EASTMAN X-RAY FILM DEVELOPMENT TIME INDICATOR"

PERIOD "A"—SEE "INDICATOR"

PERIOD "B"—SEE "INDICATOR"

PERIOD "C"—SEE "INDICATOR"

DISCARD DEVELOPER—BEGIN ANEW

FIG. 44.—*X*-ray developer exhaustion chart. A record of the films developed is kept in the squares of the chart. (Eastman Kodak Company.)

A method of accurately determining the requisite increase in the time of development required by exhaustion and contamination of the solution has been worked out by Wilsey and Norris.

Put a 5- by 7- or $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film in a cardboard exposure holder, cover the middle portion lengthwise with a strip of lead $1\frac{1}{2}$ to 2 inches in width and expose for 15 milliampere-seconds, using 85 peak kilovolts (5-inch spark gap), 28-inch anode-film distance, and a $\frac{1}{2}$ or 1 millimeter aluminum filter. A record of the exact settings of the machine for this exposure should be kept so that it may be repeated at any time. In the dark room cut this film and its black paper cover lengthwise through the middle so as to have two pieces, each with an exposed and unexposed portion.

The test depends on the determination of the time of the appearance of a line of demarcation between the exposed and unexposed portions of the film. To make the test, first take the temperature of the developing solution. Then remain in the dark room until the pupils of the eyes have dilated so that vision is acute. Partly fill a glass with developer and set it near the dark-room light. Cut two narrow strips from one piece of the exposed film and immerse one in the developer in the glass. Accurately determine the time in seconds required for the appearance of the line of demarcation. As a check, repeat with the other strip. The rest of the film should be preserved and protected for other tests.

With a tank of fresh developer determine the appearance time as described above. Divide the full normal developing time of that developer by the time of appearance of the image on the test strips. This gives what is known as the Watkins factor. For example, if the developing time be 5 minutes and the appearance time 25 seconds, the Watkins factor will be 300 divided by 25 or 12. As the developer deteriorates the appearance time on the test strips will increase. The proper time of development will be determined by multiplying the Watkins factor by the time of appearance of the image on the test strips. If the appearance time be 40 seconds, 40 times 12 is 480 seconds, or 8 minutes, the time of development in the developer at that time. Other more elaborate and more accurate methods of testing developer strength may be found in the articles referred to in the bibliography at the end of the chapter.

Defects in exposures of *x*-ray films cannot be corrected by shortening or lengthening the development. The images on an overexposed film will appear very quickly. If the development be shortened, both detail and contrast will be lacking; if carried out to the correct time, the film will be so black that except with the strongest illumination the images cannot be seen. Underexposure results in a flat film, without contrast, which no variation in development will correct. When doubt exists as to what constitutes a correct exposure, the universal practice seems to be to overexpose the films and to attempt to compensate for this by underdevelopment.

At the end of development the films should be taken from the solution, and unless the replenisher method be used, the excess liquid permitted to drip back into the tank. They should then be rinsed in water for twenty to thirty seconds and transferred to the fixing bath. They should remain in the fixer for a time twice that required to dissolve the unaffected silver from the emulsion or twice the time required for the films to become perfectly clear. Following fixation, they must be thoroughly washed to remove the chemicals of the fixing bath. This requires ten minutes in running

water or twice as long in still water. The film is then ready to be hung up to dry.

The fixing bath and the rinsing and washing water must be as cool or cooler than the developer. If the temperature of these solutions be too high, it will cause frilling and loosening of the emulsion from the base. Provisions for temperature control of the fixing bath and the wash water are just as important as for the developer.

REDUCTION OF OVEREXPOSED FILMS.

An underexposed film is rarely encountered in an *x*-ray laboratory while overexposed films are common. Overexposure and underdevelopment give a film that is grayish-black and lacking in detail and contrast. An overexposed and completely developed film often is so black that the images on it cannot be seen even with the brightest available illumination. When it is not possible to make a re-examination, some such films may be improved to such an extent as to be of diagnostic quality by a process known as reduction.

Of the preparations used for reducing films, Farmer's reducer is one of the best. It is made in two stock solutions as follows:

Stock Solution A.

Potassium ferricyanide	$1\frac{1}{4}$ oz.	37.5 gm.
Water to make	16 oz.	500 cc.

Stock Solution B.

Sodium thiosulphate (hypo) . .	16 oz.	480 gm.
Water to make	64 oz.	2000 cc.

For use, 1 oz. (30 cc.) of stock solution A is mixed with 4 oz. (120 cc.) of stock solution B and immediately diluted with 32 oz. (1 liter) of water. The solution is poured over the film, preferably in a white enameled tray. The reduction takes place rapidly so that the film should be carefully watched. When sufficient reduction has taken place, the film should be washed thoroughly before drying.

Farmer's reducer must be prepared immediately before use and discarded afterward, for it does not keep for any length of time.

Another solution that may be used for reducing overexposed *x*-ray films is a modified Belitzski reducer. The formula is as follows:

Ferric chloride	365 gr.	25 gm.
Potassium citrate	$2\frac{1}{2}$ oz.	75 gm.
Sodium sulphate (desiccated) . .	1 oz.	30 gm.
Citric acid	290 gr.	20 gm.
Sodium thiosulphate (hypo) . .	$6\frac{3}{4}$ oz.	200 gm.
Water to make	32 oz.	1 liter

The chemicals should be dissolved in the order given. The films are treated for one to ten minutes at 65° to 70° F. (18° to 21° C.) and then thoroughly washed. This formula has the advantage that it keeps well. Enough of it may be prepared to fill a narrow developing tank. It may be used over a considerable period of time to improve the quality of films that are only slightly overexposed and to clear films that have a grayish appearance from fog.

In concluding this chapter, emphasis is again placed on the importance of the correct development of films. Their immersion in the different solutions for the correct time at the correct temperature is the only way that this can be done. A correctly exposed film may be seriously impaired by improper development; no variation in development will compensate for an incorrect exposure.

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CHAPTER VI.

INTRODUCTORY EXPERIMENTS.

SKILL in roentgenographic technique requires a knowledge of the operating characteristics of x-ray machines, an understanding of the laws which govern x-ray exposures, the ability to select correct combinations of factors for exposing films of any part of the body, and dexterity in posing patients and placing films and tube so that the best roentgenograms will be obtained.

Skill of this kind requires training and experience. These probably can be acquired more quickly and thoroughly by instruction in a postgraduate school, a school of technique, or by a period of training under a competent roentgenologist. Skill may also be developed by working alone in an x-ray laboratory. With this in mind, to guide the beginner in learning roentgenographic technique and to be used in teaching, a number of experiments have been introduced in this chapter.

The first essential for satisfactory roentgenographic technique is a knowledge of the operating characteristics of x-ray machines, particularly the ones that are to be used. The most important part of this is the ability to select correct secondary voltages and milliamperages for every x-ray exposure that is to be made.

Experiments 1, 2, and 3 include the directions for making a working calibration of any x-ray machine producing full-rectified current. As will be explained later, it is not possible to perform these experiments on all equipments. The figures given in the tables and charts were obtained by performing these experiments as they are given and only apply to one particular machine. When performed on any other, peculiarities in construction and operative characteristics will give other results.

Experiments 4, 5, and 6 are included to illustrate and explain the laws which govern roentgenographic exposures. A thorough knowledge of these laws is the second requisite for skill in technique. In Chapter VII is introduced the idea of establishing a basic roentgenographic technique from which, by using these laws, the greater part of all technique may be derived. In order that the modifications of this basic technique or any modification of any other technique be understood, it is essential that these laws be thoroughly comprehended. For this reason it is urged that the student perform these experiments and make a careful study of the explanation which follows each one.

Experiment 1.

Object.—To study the voltages of the electric current in the low-voltage (primary) and high-voltage (secondary) circuits of an *x*-ray machine, and, with a constant milliamperage, to determine secondary voltage values for certain autotransformer settings and voltmeter readings.

Each of the early *x*-ray machines was equipped with a blunt-point spark gap, and testing the voltage with the gap was a part of most *x*-ray exposures. Only in this way could an idea of the vacuum in a gas tube be obtained. With the tube activated, the spark gap was closed until the electricity crossed the gap instead of passing through the tube. It was said that the tube would back up a gap of so many inches, meaning that a voltage represented by that length of gap was necessary to overcome the vacuum in the tube. A tube backing up a long gap, in which the vacuum was high, was called a hard tube; and one requiring a low voltage as represented by a shorter gap was called a soft tube. The resultant *x*-rays were said to be hard or soft, depending on the vacuum in the tube. This designation of high- or low-voltage *x*-rays is sometimes used even now. The penetrability of the rays was roughly measured by the spark gap measurement necessary to activate the tube that produced them.

When Coolidge tubes with a constant vacuum replaced gas tubes, frequent voltage determinations were no longer necessary; but for some time blunt-point spark gaps were included as a part of the equipment. When the inaccuracies of blunt-point spark-gap determinations of voltage were fully appreciated and voltmeters had been installed in the primary circuits of all transformer-type machines, calibrations were made of the machine in terms of voltmeter readings by using the more accurate sphere gap. Few machines were equipped with a sphere gap, and portable sphere gaps were used, the calibrations most often being made by factory or service representatives. The information from these tests was incorporated in a calibration chart. This chart gave voltmeter readings that would result in peak kilovolt values in the secondary circuit with different milliamperages.

A determination of voltage values with self-rectifying and half-wave rectifying apparatus cannot be made with a spark gap, nor can one be made with the fully shock-proof apparatus, one with cables from the transformer to the tube and a shock-proof housing for the tube. With the half-wave rectifying machines, the inverse voltage (that attempting to pass from anode to cathode through the tube) is higher than the direct voltage, and on the fully shock-proof

equipment there is no place to attach the sphere gap. In apparatus of these kinds voltage indicators include the autotransformer settings, voltmeter readings, and illuminated dials on the autotransformer switches, and calibrations are made at the factory during manufacturing. Of course, there is no need for calibration of a machine with full automatic control with stabilization of the primary and secondary voltage and amperage.

It is appreciated that on many forms of x-ray machines Experiments 1 and 3 cannot be performed. However, the experiments are retained, for there are still many machines in use on which they can be performed, and the voltage study incorporated in them is of the greatest importance to the operator of any kind of x-ray machine.

Any hot-cathode x-ray tube may be used. A medium or broad focus universal Coolidge tube is best. In using any other type, great care should be exercised not to exceed the capacity of the tube.

In the primary circuit of an x-ray machine there is always one, usually two, indicators of primary voltages. One of these is the studs or buttons on the multiple-pole switch or switches connected with the autotransformer; the other is the voltmeter. Multiple-pole switches may have illuminated dials attached to them with a special line-voltage regulator and a line-voltage meter. Of these indicators perhaps the voltmeter is preferable, for fluctuations in primary voltage will be reflected in its readings and not be apparent from control settings. The calibration must be made in terms of one or both of these as indicators of primary voltage. In performing this experiment, beginning with the lowest, first select autotransformer settings, voltmeter readings, or both, at definite intervals, and enter them in a chart like Table II. Then proceed as follows:

1. Close the supply-line and main switches and start the motor; or if a valve-tube machine, close the filament switch. If necessary close the filament switch of the x-ray tube. Place the autotransformer control on the lowest button. Close the x-ray switch and adjust the filament regulator so that exactly 20 milliamperes are passing through the tube. The milliamperage should be kept constant at 20 throughout the experiment.

2. Close the x-ray switch and slowly bring the terminals of the spark gap nearer each other until a spark jumps across the gap, then open the x-ray switch. Note the reading of the needle of the voltmeter in the primary circuit. If the spark gap be a point gap, measure the width of the gap; if a sphere gap, read the number of peak kilovolts from the scale. These will give the potential of the high-voltage current measured as spark gap in inches or as peak kilovolts, and the voltmeter reading for the lowest autotransformer setting on the machine.

TABLE II.

Autotransformer controls.	Voltmeter readings.	Peak kilovolts.
A 1	58	50
A 3	64	56
B 1	70	62
B 3	78	72
C 1	84	79
C 3	90	85
D 1	97	95

TABLE II.—An example of the table showing voltmeter readings and secondary voltage determinations to be prepared during the performance of Experiment 1. Note that the machine has two autotransformer controls and a voltmeter calibrated in peak kilovolts. The voltage determinations were made with a portable sphere gap.

3. Prepare a table similar to Table II and fill in as many of the columns as possible. These should include at least the control settings, the voltmeter readings, and the determinations of the voltages of the secondary current either as spark gap in inches or as peak kilovolts.

4. Proceed in a like manner with a determination of the secondary or high-voltage values produced by each of the control settings and voltmeter readings previously selected. The most accurate determinations are made when the current is flowing through the tube and the terminals of the gap are approximated until the current arcs from terminal to terminal. Carefully record all observations in the table.

Discussion.—The potential of the current in the primary circuit of an x-ray machine is measured in volts and varies from about 60 to 220 volts. It is varied or changed by the autotransformer through which the current passes between the supply line and the primary coil of the high-tension transformer. The number of different primary voltages that are available for use depends on the construction of the autotransformer. Since each primary voltage with a particular milliamperage will give a certain voltage in the secondary circuit, the number of secondary voltages also depends directly on the construction of the autotransformer in the primary circuit.

Unfortunately the construction of the control devices in the primary circuits of x-ray machines has not been standardized, different manufacturers making differently constructed instruments. Transformer type mechanically rectified machines formerly made by two well-known manufacturers have autotransformers which begin at 60 or 80 volts and increase the primary voltage in steps of 5 volts. On these machines, using 20 milliamperes, increasing the primary current in 5-volt steps will increase the secondary voltage in steps of approximately 3½ peak kilovolts (2½ effective kilovolts or ¼-inch spark gap). Between the lowest voltage and 100 peak kilovolts (2- and 6-inch spark gap), which includes the

range of secondary voltages useful in roentgenography, steps of this kind will give at least 17 useful secondary voltages, a number that has been found adequate for most roentgenographic work.

Other machines have differently constructed autotransformers. One familiar type has secondary voltage intervals of 8 peak kilovolts, which only provides about 8 or 9 secondary voltages available for use. An attempt to use the rheostat on this machine was so unsatisfactory that its use was abandoned. Machines which have been constructed recently, particularly those with valve-tube rectification, have much finer steps in the autotransformer, giving smaller high-voltage intervals in the secondary circuit. In some of these the intervals are as small as 1 peak kilovolt; others have 2 peak kilovolt steps.

Primary voltmeters are of three kinds: one with the scale reading in alternating current volts, one with the scale reading in effective or peak kilovolts, and the third with the scale showing arbitrary divisions, usually from 1 to 100, and often called a potential indicator (Fig. 10, p. 29). The last two are alternating current voltmeters similar to the first, differing only in the calibrations on the scale. When reading in kilovolts, the scale is intended as an indicator of effective or peak kilovolts which will be produced in the high-voltage circuit by that particular primary voltage.

With autotransformer control, a voltmeter measurement of the primary current is an accurate indicator of the secondary voltage. When it has been determined that a certain voltmeter reading will give a particular kilovoltage with a known milliamperage, if the milliamperage be the same, at any future time that kilovoltage can be secured by setting the primary controls to give the same voltmeter reading. This makes it possible to calibrate *x*-ray machines by determining the voltmeter readings that will give different kilovoltages with different milliamperages and afterward to use the voltmeter readings in selecting high-voltages for impression on the *x*-ray tube.

In the high-voltage or secondary circuit of an *x*-ray machine the voltage commonly is measured by some form of spark gap. Of these there are three chief forms: one in which the gap terminals are needle points, one in which the terminals are sharp or moderately blunt points, and one in which the terminals are in the form of spheres. Of these the needle-point gap (new sewing needles) and those having the terminals made of spheres of various sizes have been more or less standardized. The American Institute of Electrical Engineers recommends the use of needle points for voltages between 15 and 70 peak kilovolts and the use of spheres of various sizes for voltages varying between 15 and 550 peak kilovolts, one

with spheres 62½ millimeters in diameter being suitable for voltages between 15 and 120 peak kilovolts, which includes the range useful in roentgenography. A needle-point gap is not especially suitable, for needles are usable only four or five times before the points become worn and the gap no longer accurate.

The use of a point spark gap (sharp or moderately blunt points) for the measurement of high potential electric voltage was originated by the manufacturers and users of *x*-ray equipment. Practically all machines of older manufacture are equipped with such instruments by means of which measurements of voltage in inches of gap may be made. Measurements made by them admittedly are somewhat inaccurate, yet the sanction of years of usage warrants a consideration of this form of voltage measurement.

The inaccuracies of point-gap measurements are due to several causes. One of the chief of these is a lack of standardization in the construction of the gap, each manufacturer adopting and following his own method of construction. The standard established by one manufacturer, for example, was the use of $\frac{3}{16}$-inch brass rods tapered to $\frac{1}{16}$-inch at the point. A gap of this sort may change its characteristics from the heat at the point tips gradually burning off the metal and changing the size and shape of the gap terminals.

Point-gap measurements also are influenced by the character of the potential, the density of the air, the humidity, the temperature, and other factors. Of these the most important is air density which is caused chiefly by differences in altitude. Markley found that a potential that would give a 6-inch gap at sea level would give an 8.7-inch gap at an altitude of 7500 feet, that 100 peak kilovolts would give a 6-inch gap at sea level, but that at 7500 feet elevation only 78.7 peak kilovolts are required for a 6-inch gap. He found that the effect of humidity is considerably less than the effect of altitude, the greater the humidity the shorter the gap for a given peak kilovoltage.

Temperature, humidity, and air density also influence sphere-gap measurements, but when corrections are made for the differences in air density due to altitude, the other factors may be disregarded.

Even sphere gap readings of the voltages in the secondary circuit of some *x*-ray machines with mechanical rectifiers are not always accurate. It has been found that measurements of the voltage from the terminals of the transformer may differ materially from measurements taken at the terminals of the *x*-ray tube. This is attributed to high frequency disturbances originating at the terminals of the rectifier and to some condenser action of the tubing in the overhead system. Inasmuch as the sphere gap measures the

highest voltages, these stored-up voltages may give a result higher than the actual and useful voltage values.

Even with these discrepancies in mind, it is apparent that the most accurate voltage determinations are those made with a suitable sphere gap that has been corrected for altitude. For this reason Experiments 1 and 3 should be performed with a sphere gap. If a sphere gap is not available, however, or if one cannot be obtained for performing the calibrations given in these two experiments, then they should be performed with whatever form of spark gap the equipment includes. If the variations in point-gap readings be remembered and the determinations of voltage as spark gap in inches be used in conjunction with a method of measuring the x-ray output of a given x-ray machine (to be introduced later), point-gap calibrations may be made the basis for a very satisfactory roentgenographic technique.

At the present time peak kilovoltage determined by means of a sphere gap has almost completely superseded point-gap determinations in roentgenology. The former has completely displaced the latter in roentgen therapy, but point-gap determinations still are used to some extent in roentgenography. It is extremely difficult to express a voltage value both in peak kilovolts and in spark gap in inches. In an attempt to determine comparative values, it was found that there was no standard of published data that could be accepted as authoritative. Tables collected from different sources give widely divergent comparative values. For example, the value in peak kilovolts for a 3-inch spark gap varies from 55.5 to 63 peak kilovolts, and that for a 5-inch gap from 77.8 to 88 peak kilovolts. One method of arbitrarily selecting comparative values is as follows:

Shearer gives a chart showing the approximate relation between effective kilovolts and spark gap for moderately blunt points in which a 2-inch gap is equal to 30 kilovolts and each additional inch of gap to $6\frac{1}{2}$ inches adds 10 kilovolts. This would make a 5-inch gap equal 60 kilovolts, etc. Effective kilovolts may be changed to a value in peak kilovolts by multiplying by 1.41. Thus a 5-inch spark gap or 60 effective kilovolts would be equal to 84.6 peak kilovolts, a $\frac{1}{4}$-inch spark gap to $3\frac{1}{2}$, a $\frac{1}{2}$-inch spark gap to 7 peak kilovolts, etc.

Experiment 2.

Object.—To study the amperage of the current in the filament circuit and the milliamperage of the current in the high-voltage circuit of an x-ray machine.

This experiment need not be performed on an equipment that includes a stabilizer that will give any desired milliamperage at any

voltage. The stabilizer may be either in the primary or the secondary of the filament circuit, or in the secondary of the filament and in the high-voltage circuits. It should be performed on all equipments that do not include a stabilizer and on those with a stabilizer but which require adjustments of the filament regulator for different milliamperages. Prepare a table similar to Table III.

1. Start the machine and adjust the controls to the lowest setting or voltmeter reading on the machine. Close the magnetic switch and adjust the filament regulator so that the milliamperemeter reads 10. Read the number of amperes in the filament circuit from the amperemeter, or the position of the needle on the filament meter, and the position of the filament regulator as shown on the filament scale. Enter these readings in the table.

TABLE III.

	Peak kilovolts.						
MA.	30.	40.	50.	60.	70.	80.	90.
10 . . .	3.65	3.62	3.60	3.60	3.58	3.57	3.55
20 . . .	3.85	3.84	3.83	3.80	3.80	3.78	3.77
30 . . .	3.95	3.93	3.92	3.90	3.90	3.89	3.88
50 . . .	4.30	4.30	4.28	4.27	4.25	4.24	4.23
75 . . .	4.45	4.44	4.42	4.40	4.40	4.38	4.37
100 . . .	4.60	4.58	4.57	4.55	4.54	4.52	4.50

TABLE III.—An example of a table showing filament amperes for different milliamperage and voltage values obtained during the performance of Experiment 2.

2. With the same control settings and voltmeter readings used in Experiment 1, in a like manner proceed with the determination of the number of amperes in the filament circuit, and in steps of 10, the readings of the filament scale for the higher milliamperages permitted by the capacity of the tube. About two seconds are necessary for the indicator needle in a milliamperemeter to come to rest and permit an accurate reading of its position. By studying the rating chart of the tube, the permissible voltages and milliamperages may be determined. Care should be taken not to overload and damage the tube. Extra high milliamperages must not be used unless the machine be equipped with a ballistic milliampere-second meter to measure the current of short exposures at high milliamperages.

Discussion.—The current through the filament of a hot-cathode *x*-ray tube is of 12 to 15 volts, varying from 3 to 5 amperes. From the supply line the voltage is reduced by the filament transformer, and the amperage is controlled by the filament regulator. The current through the filament heats it, causing it to give off electrons. These carry the high-voltage current from the cathode to the anode of the tube. The heat of the filament, the quantity of electrons, and the number of milliamperes of high-voltage current all depend on the

filament current as measured in amperes. With a particular tube operating at a certain voltage, a given amperage through the filament circuit always will give approximately the same milliamperage through the tube.

A careful study of the table prepared in this experiment will show that the milliamperes increase with an increase in the amperes of filament current and that the amount of filament current necessary to give a certain milliamperage varies slightly, usually dropping, as the voltage through the tube is increased. On machines that do not have an amperemeter in the filament circuit, readings of the filament current in amperes cannot be made. Dependence must then be placed on the readings of the scale on the filament regulator or of a filament meter when one is present. The scale usually is purely arbitrary and means nothing except that it enables an operator to repeat a certain setting.

Because of line fluctuations, neither a particular filament amperemeter nor scale reading is absolutely accurate (see p. 56). Long exposures sometimes permit adjustment to the exact milliamperage during the exposure; short exposures do not. Because gross fluctuations may be corrected by a meter reading, this is more accurate than a scale setting in giving a desired milliamperage through an *x*-ray tube. Fluctuations and variations in milliamperage can only be prevented by an efficient stabilizer; thus the importance of such a piece of accessory apparatus is emphasized.

There is a difference in the resistance of the filaments in different hot-cathode tubes. Therefore different filament amperages may be required for a particular milliamperage in different tubes. If more than one tube be used for radiographic work, if a double focal spot be used, or if a tube be replaced, Experiment 2 should be performed for each.

The tables prepared in this experiment, one for each tube used, should be neatly copied and preserved for reference. If they be fastened to the wall near the control stand, they may be referred to at any time. From them may be obtained the filament amperemeter reading or scale reading for any milliamperage with any voltage. Their use will make it unnecessary to do much testing of the milliamperes through the tube before exposures are made, thus prolonging the life of the tube.

EXPERIMENT 3.

Object.—To study the changes in the voltage of the electric current in the high-voltage circuit of an *x*-ray machine that are caused by changes in the milliamperage, and to determine, with different

milliamperages, the secondary voltages given by the autotransformer and indicated by the voltmeter in the primary circuit.

This experiment is a continuation of Experiment 1, and the same restrictions and precautions apply. Since the results may be used with any hot-cathode tube, a medium or broad focus universal Coolidge tube or a high-capacity tube of any other kind should be used. The tube must not be overheated nor used above its rated capacity. It probably will be necessary to make the voltage determinations for one voltmeter reading at the various milliamperages and then allow the tube to cool before proceeding with the next. The determinations should include 10, 20, 30, and higher milliamperages if the tube permits. If the tube capacity be as much as 100 milliamperes, the study may be carried to this milliamperage. Amperages much above 100 milliamperes should not be used unless a ballistic milliampere-second meter is available for testing at very short exposures.

TABLE IV.

		Peak kilovolts with the following milliamperes.				
A.T.C.	V.R.	10.	20.	30.	50.	100.
A 1	58	54	50	55	37	
A 3	64	60	56	52	41	
B 1	70	66	62	59	51	32
B 3	78	75	72	69	61	36
C 1	84	83	79	76	67	47
C 3	90	90	85	82	75	54
D 1	97	99	95	92	84	62
D 3	103	..	..	97	91	67
E 1	109	..	..	..	97	72
E 3	115	..	..	..	..	77

TABLE IV.—Example of the table showing different voltage values for various voltmeter readings with different milliamperages prepared during the performance of Experiment 3. The voltage determinations were made with a portable sphere gap. A.T.C., autotransformer controls; V.R., voltmeter readings.

1. Prepare a table similar to Table IV and enter in the first, second, and fourth columns the control settings, voltmeter readings, and the voltage measurements determined in Experiment 1 and shown in the table similar to Table II prepared during the performance of that experiment.

2. Start the machine and place the controls on the lowest autotransformer setting. Determine the milliamperes through the tube and adjust the filament regulator so that exactly 10 milliamperes are flowing. Then make a determination of the voltage in the secondary circuit as in Experiment 1. It will be found that the voltage is higher than that obtained with 20 milliamperes in Experiment 1. This should be measured and the result entered in column 3 in the table.

3. Increase the milliamperes to 20 and determine the secondary

voltage with the spark gap. This should be the same as previously determined in Experiment 1.

4. With the same settings make determinations of the secondary voltages with 30 and 50 milliamperes and if the tube permits with higher milliamperages.

5. Proceed with each of the other control settings and voltmeter readings shown in columns 1 and 2 in the table and make voltage determinations with 10, 20, 30, 40, and, if possible, with 50 and 60, and higher milliamperages. Enter all measurements in the table.

Discussion.—In Experiment 1 voltmeter readings, control settings, and high-voltage values were determined at intervals from the lowest setting to about 100 peak kilovolts (6-inch spark gap). In that experiment the milliamperage was kept constant at 20. In the discussion it was stated that, with the milliamperage constant, voltmeter readings are an accurate indicator of voltages in the secondary circuit, and that control settings also may be used as secondary voltage indicators. Experiment 3 shows the changes that are produced in the voltage in the high-voltage circuit caused by changes in the milliamperages. Beginning with certain voltage and milliamperage values, using a smaller number of milliamperes will increase the voltage; using a larger number of milliamperes will decrease the voltage in the secondary circuit.

For machines equipped with a voltmeter and using autotransformer control, from Table IV a chart like Fig. 45 may be made. The ordinates of this chart are the voltmeter values used in Experiments 1 and 3. The abscissæ show voltages in peak kilovolts. Voltages in spark gap in inches may be used equally well. On the chart there is a line for each milliamperage used in Experiment 3. These lines are made by placing a dot at the crossing of the ordinate for each voltmeter setting with the abscissa from each voltage determination with each milliamperage. Connecting the dots for each milliamperage gives the lines on the chart.

This chart graphically gives the voltage changes caused by changes in milliamperage. A study of it shows that, with the particular machine used in obtaining the illustrative figures for the experiment, changing the milliamperes from 10 to 50 with each control setting and voltmeter reading causes a voltage drop of 15 peak kilovolts; that changing the milliamperes from 10 to 30 causes a voltage drop of approximately 7 peak kilovolts, and that increasing the milliamperage from 10 to 100 causes a voltage drop of over 30 peak kilovolts. These changes are slightly greater at the lower than at the higher initial voltages.

From this chart there also may be obtained the voltages that will be given by each autotransformer setting and voltmeter reading

on the machine with any milliamperage used in the experiment. When used for this purpose, following the ordinate for each voltmeter reading from the left of the chart until it crosses the lines for the different milliamperages will give (from the abscissæ at the bottom) the different peak kilovolt values. These may be made into the table shown in Table V. While such a table may be made by testing each setting separately, one derived from a chart like Fig. 45 is just as accurate, considerably less time consuming, and a great deal less likely to damage the tube. Such a chart constitutes a calibration chart of the machine for which it is prepared.

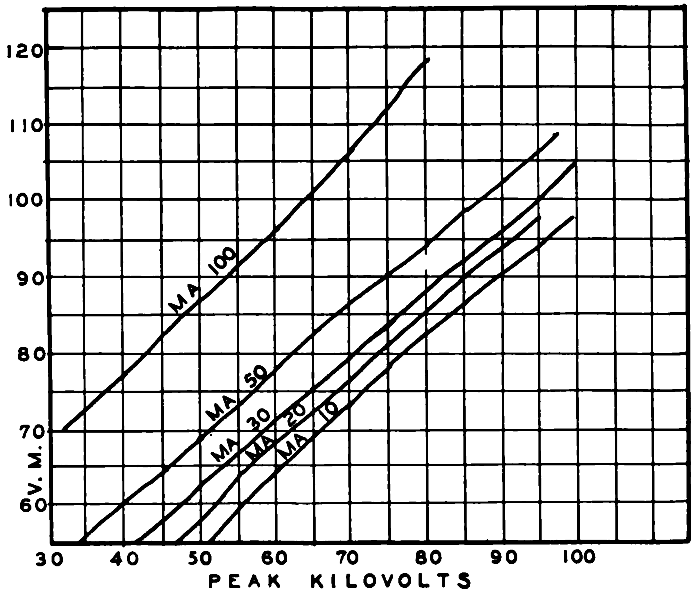

FIG. 45.—A chart made from the results of Experiment 3 as shown in Table IV. From it may be obtained a voltmeter reading giving a particular voltage value with any of the milliamperages used in the experiment. The abscissæ are voltages in peak kilovolts; V.M., voltmeter readings. The calibration given in Table V was obtained from this chart.

Voltage changes such as these are common to all x-ray machines, but in different machines there is considerable variation in the amount of voltage change. Using only autotransformer control, one machine that has been tested does not give more than 13 peak kilovolts drop in increasing the milliamperage from 10 to 100. The same increase in milliamperage on a similar machine causes a voltage drop of 28 peak kilovolts, or 2 inches, as measured by a point spark gap.

It is impossible to perform Experiments 1 and 3 with a unit type machine and with one having a single valve-tube rectifier in the

secondary circuit. In these machines the suppressed half of the high-voltage current has a higher voltage than that which passes through the tube, and the use of a spark gap is apt to puncture the rectifying or x-ray tube. The information that may be obtained from these experiments is provided by the manufacturers either

TABLE V.

A.T.C.	V.R.	P.K.V. with the following milliamperes. 10.	20.	30.	50.	100.
A 1	58	54	50	45	37	
A 2	61	57	53	49	41	
A 3	64	60	56	52	45	
A 4	67	64	60	56	48	
B 1	70	66	62	59	51	32
B 2	74	71	67	63	56	36
B 3	78	75	72	69	61	41
B 4	81	79	76	73	64	44
C 1	84	83	79	76	67	47
C 2	87	86	82	79	71	50
C 3	90	90	85	82	75	54
C 4	94	95	90	87	80	57
D 1	97	99	95	92	84	62
D 2	100	..	..	95	87	64
D 3	103	..	..	97	91	67
D 4	106	..	..	..	95	70
E 1	109	..	..	..	97	72
E 2	112	..	..	..	..	75
E 3	115	..	..	..	..	77
E 4	118	..	..	..	..	80

TABLE V.—A calibration chart of an x-ray machine prepared during the performance of Experiment 3. This was prepared from Fig. 42. From this chart may be obtained the correct voltmeter readings for different secondary voltages with different milliamperages. In many instances an exact voltage cannot be obtained but it can be closely approximated. A.T.C., autotransformer control settings; V.R., voltmeter readings.

TABLE VI.

A.T.C.	Rh.	V.R.	P.K.V. with the following milliamperes. 10.	20.	30.	40.
1	15	9.0	61	50	42	32
2	15	11.5	68	62	52	44
3	15	14.0	76	70	63	54
4	15	17.0	82	78	72	64
5	15	19.5	88	86	82	73
6	15	23.0	96	94	88	80
7	15	26.5	104	100	94	86

TABLE VI.—A table prepared during the performance of Experiment 3 on a machine with only a few autotransformer settings in the range of voltages used in roentgenography. On this machine the voltmeter is of little value in determining secondary voltage values. The control settings are used for this purpose. The attempt to obtain smaller voltage steps by the use of a rheostat was so unsatisfactory that it was abandoned.

in the form of a chart showing voltmeter readings for different voltages with various milliamperages or in the form of a specially calibrated voltmeter. One concern making valve-tube apparatus has added a small milliampere scale at the left or zero side of the voltmeter. Before the main switch is closed, if the indicator hand of

the voltmeter be placed on the setting for the milliamperage that is to be used, during the exposure the voltmeter will read in terms of peak kilovolts with that milliamperage in the secondary circuit. This is an ingenious device that, if accurate, should answer the purpose of the calibrations given in these experiments.

Many kinds of newer x-ray machines with valve-tube rectification have illuminated dials attached to the shafts of the multiple-pole switches of the autotransformer, the numbers on the dials giving the peak kilovolts that will be delivered to the tube with that setting of the controls. These machines have a third multiple-pole switch in the controls that is connected in the primary of the autotransformer (see p. 25 and Fig. 7). On these machines this switch is used to increase or decrease the primary voltage to compensate for changes due to different milliamperages through the tube. It is sometimes called a line-voltage regulator and it has a line-voltage meter connected to it. The line-voltage meter may be calibrated with a sphere gap, usually at the time of installation, to indicate the amount of primary voltage that must be added or subtracted with different milliamperages. The line-voltage switch also adjusts the primary current of the filaments of the valve tubes, adjusting the valve-tube current to the milliamperage of the high-voltage current that the tubes will be expected to rectify.

In apparatus of this kind the numbered dials on the autotransformer switches have been found to give accurately the high-voltage values in peak kilovolts. With such apparatus a calibration chart is unnecessary.

The quality or penetrability of Roentgen-rays depends on the voltage with which they are produced. Relatively slight errors in voltage will give marked errors in the exposure of films. Therefore the selection of the proper voltage probably is the most important and difficult factor in roentgenography. Many different combinations of voltage and milliamperage may be used in exposing films of different parts of the body. While milliamperes may be read at any time from the meters, the control settings and voltmeter readings must be adjusted for the proper voltages before the exposures begin. Therefore, whenever necessary, calibrations like those in Experiments 1 and 3 must be made as carefully as possible.

Experiment 4.

Object.—To demonstrate the laws that, if the other factors remain constant, the intensity of an x-ray exposure as measured by its photographic effect, varies directly as the milliamperes through the tube, and directly as the time of the exposure.

1. Mark off with a pencil ten areas of equal size on a 6½- by 8½-inch film cardboard exposure holder, five on each side of a line that divides it lengthwise into two equal parts. Beginning at the upper left corner and extending downward, number the areas on the left half from 1 to 5 and those on the right half from 6 to 10. Put a film with its black paper cover in the holder.

2. Put a small cone in the tube stand, start the machine, and adjust the controls for a secondary voltage of 50 peak kilovolts or its equivalent, and 5 milliamperes. Use an anode-film distance of 30 inches. Place a lead figure "4" on area 1, cover all the remainder of the film holder with sheet lead or lead rubber, and expose the first area for six seconds.

3. Using the same voltage and anode-film distance, continue exposing the areas one at a time using the milliamperes and time given in the following table. If it be necessary to test the milliamperage, be certain that all of the film is covered with lead.

TABLE VII.

Area No.	Ma.	Time in seconds.
1	5	6.0
2	10	3.0
3	15	2.0
4	20	1.5
5	30	1.0
6	5	2.0
7	10	2.0
8	15	2.0
9	20	2.0
10	25	2.0

4. When the exposures have been completed, develop the film until the lightest area, No. 6, shows some blackening, disregarding the density of the other areas (Fig. 46). Fix, wash, and dry the film.

Discussion.—The finished film will show that areas 1 to 5 are of nearly the same density or degree of blackening, or that essentially the same amount of the silver in the emulsion has been affected by the Roentgen-rays. Areas 6 to 10 will show a progressive increase in the density of the different areas. In the exposure of areas 1 to 5, the milliamperes through the tube have been increased from 5 to 30, but the time has been correspondingly decreased. For each of these areas, a quantity of Roentgen-rays equal to 30 milliampere-seconds has been used. In increasing the milliamperes from 5 to 30, there has been some decrease in the voltage through the tube, but this will not materially change the results. For the last five areas, the quantity of Roentgen-rays has been increased from that represented by 10 milliampere-seconds to that of 50 milliampere-

seconds. This graded increase in quantity should cause a definite and regular increase in the density or blackening of these areas. The density of area 7 should be twice that of area 6; that of area 8, three times; of 9, four times, and that of area 10, five times that of area 6.

This experiment should show, therefore, that with voltage and distance constant, the photographic effect of x-ray exposures varies directly as the number of milliampere-seconds used. If the milliamperes be kept constant, it varies directly as the variations in the time of the exposure; if the time be kept constant, the photographic effect varies directly as the variations in milliamperes. Thus if an exposure be made with any milliamperage for a certain number of seconds, doubling the time will double the photographic effect; halving the time will reduce the effect to one-half. Or if an exposure be made with a particular milliamperage for a certain time, increasing or decreasing the milliamperes will correspondingly increase or decrease the photographic effect.

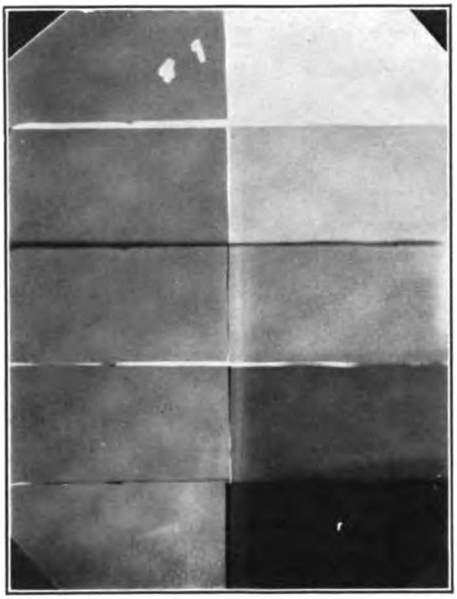

FIG. 46.—A photographic reproduction of a film exposed during the performance of Experiment 4. Those from Experiments 5 and 6 are similar.

In calculating such variations in photographic effect, it is convenient to multiply the milliamperes by the time in seconds and use milliampere-seconds, thus using one number instead of two.

Experiment 5.

Object.—To demonstrate the effect of a change in anode-film distance, and prove the law that, other factors remaining constant, the intensity of an *x*-ray exposure varies inversely as the square of the anode-film distance.

Place a film in an exposure holder as in Experiment 4. Use 10 milliamperes and a voltage of 50 peak kilovolts or its equivalent. Expose the different areas with the distances and times given in the following table. For the shortest distance the cone must be removed from the tube stand; for the longest the film must be put on a chair or on the floor. Measure all distances with a tape measure from the target, focal spot, or anode of the tube to the film. Be certain that the film is numbered to correspond to the number of the experiment.

Table VIII.

Area No.	Distance in inches.	Time in seconds.
1	10	0.5
2	20	2.0
3	30	4.5
4	40	8.0
5	50	12.5
6	10	1.0
7	20	1.0
8	30	1.0
9	40	1.0
10	50	1.0

Develop the film until the lightest area, No. 10, shows some blackening. Fix, wash, and dry it.

Discussion.—On this film, areas 1 to 5 will have approximately the same density, while areas 6 to 10 will decrease in density from the first to the last. In both series of five exposures the distance was increased from 10 to 50 inches. In the first series the increases in distance were compensated for by increases in the time of the exposures. In the second series the time of the exposures remained constant.

Roentgen-rays originate at the focal spot of the anode of an *x*-ray tube, spread out in all directions in a hemisphere of which the focal spot is the center, and travel until they are intercepted by some object or substance in their path. At a certain distance from the tube anode, a given area of surface will intercept a certain quantity of the rays. If this same area be moved nearer or farther from the tube, the quantity of rays striking it will have a definite relationship to the distance it has been moved.

For example, in the experiment, area 1 at 10 inches from the anode, received a certain quantity of rays that produced a blackening of the film when it was developed. Moving the tube for area 2 so as to increase the distance to 20 inches caused the rays to spread out so that they cover an area four times as large (Fig. 47). With the same time of exposure, area 2 would receive only one-fourth as much radiation as area 1. To keep the radiation constant, as measured photographically, the exposure of area 2 was increased to four times that of area 1.

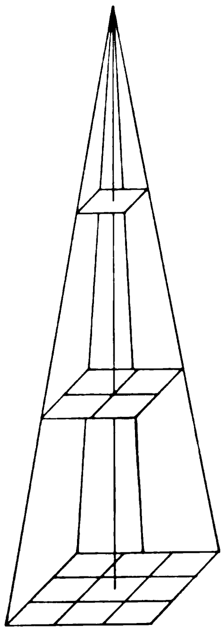

FIG. 47.—Diagram illustrating the inverse-square law. A pyramidal-shaped beam of Roentgen-rays will strike an area of a certain size at a given distance. At twice the distance the beam will cover an area four times larger; at three times the distance it will cover an area nine times larger.

Area 1 was exposed at a distance of 10 inches, the square of which is 100; area 2 was exposed at a distance of 20 inches, the square of which is 400. These are to each other as 100 is to 400 or as 1 is to 4. The exposures of areas 3, 4, and 5, compared with that on area 1, were at the ratios of 9, 16, and 25, which are the same as the squares of the distances used. It may be said, therefore, that the relationship of exposure times of two areas, other factors remaining constant, varies as the square of the anode-film distances.

In exposing areas 6 to 10 the time remained constant, but the distances were increased. Area 7 received one-fourth as much radiation intensity as area 6. The squares of the distances are 100 and 400. Inverting these two numbers, area 6 received an intensity of 400 compared to 100 for area 7, or a ratio of 4 to 1. Therefore, with the other exposure factors constant, the intensity of x-ray exposures varies inversely as the squares of the anode-film distances.

This law is one of the most important and most useful in roentgenography. If the factors that will give a satisfactory film at one distance be known, and the intention be to expose a film at a different distance the voltage and milliamperage can be kept constant and the time of the exposure at the new distance calculated from the following formula: $T:T'::D:D'$, where T is the known time, T′ the unknown time, D the known distance, and D′ the desired distance.

For example, if five seconds be appropriate for a 35-inch distance, the time for 25 inches would be determined as follows:

$$5:T'::35^2:25^2$$
or $$5:T'::1225:625$$
or $$1225\ T = 3125$$
or $$T' = \frac{3125}{1225} \text{ or } T' = 2.5$$ seconds, the appropriate time for 25 inches.

Inasmuch as the intensity of an exposure varies directly as the milliamperes used, if the milliamperes at one distance be known, using the same time, a proper milliamperage for any other distance may be calculated in a similar manner. It perhaps is preferable to combine the milliamperes and time to form milliampere-seconds and make the calculation using milliampere-seconds. When once determined, any combination of milliamperes and time may be used so long as they give the appropriate milliampere-seconds.

For example, if 100 be the proper number of milliampere-seconds at 35 inches in distance, and the number at 25 inches be sought, the calculation would be as follows:

$$100:MAS'::35^2:25^2$$
or $$100:MAS'::1225:625$$
or $$1225\ MAS' = 62500$$
or $$MAS' = \frac{62500}{1225} \text{ or } MAS' = 51.$$

An exposure using 51 milliampere-seconds at a 25-inch distance would give the same radiation intensity as 100 milliampere-seconds at 35 inches. The latter may have been produced by 20 milliamperes for five seconds; the 51 may be closely approximated by 25 milliamperes for two seconds.

Based on this law, charts showing changes in time, milliamperes, or milliampere-seconds necessary to compensate for changes in distance, may be prepared and used for reference. Such charts are shown in Figs. 48 and 49. From them may be obtained a factor to be used in calculating a new value in either time, milliamperes, or milliampere-seconds, at any distance from 15 to 35 inches, when the value of these at any other distance is known. They may also be used for determining a new distance appropriate for any desired number of milliampere-seconds.

In these charts the distances are given as the ordinates; the abscissæ are the factors. In both charts the known factors are represented by the abscissa 1. Fig. 48 is to be used when the distance is to be increased and Fig. 49 when it is to be decreased. The following examples explain the method of using these charts.

If the milliamperes and time be known for a proper exposure at 15 inches, and an exposure at a greater distance be desired, begin at 15 on the line 1, Fig. 48, and follow the line of the chart upward and to the right until it crosses the ordinate for the desired distance, obtaining the number to be used as a multiplier from the abscissæ.

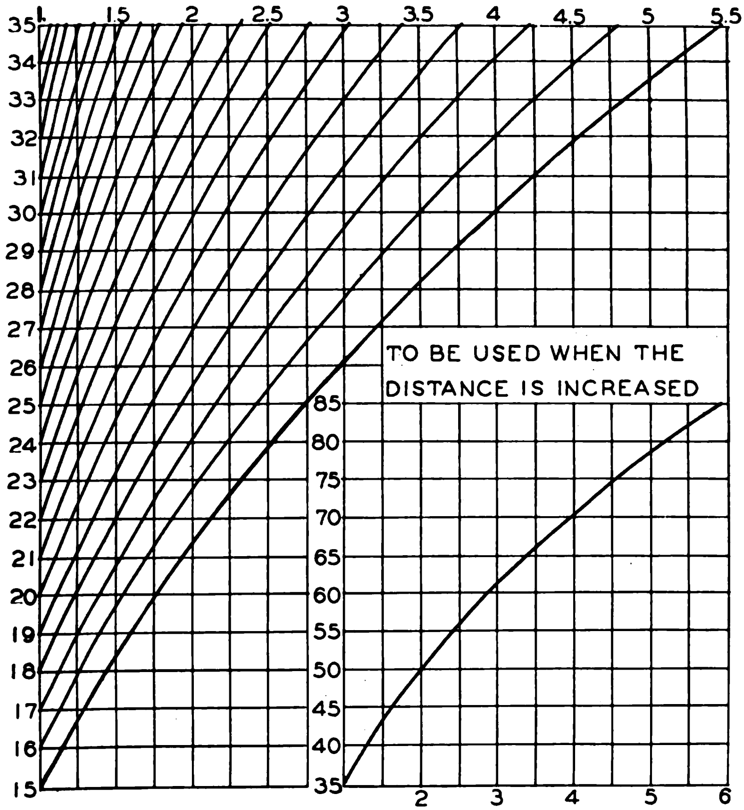

FIG. 48.—A chart, based on the inverse-square law, from which may be obtained a factor for multiplying the time, milliamperes,or the milliampere-seconds of a known x-ray exposure when the distance is to be increased. The larger section of the chart shows all distances between 15 and 35 inches. The factor is obtained from the abscissæ on the top of the chart. The smaller section is based on a known exposure at a 35-inch distance and gives the factors necessary for increases in distance up to 85 inches. The factors are the abscissæ on the bottom of the chart.

At 20, 25, 30, and 35 inches, the milliampere-seconds would need to be multiplied by 1.7, 2.7, 4, and 5.5 respectively. Again if the factors be known for an exposure at 25 inches and 35 inches be a preferable distance, begin at 25 on the line 1 and follow it to the ordinate for 35, the proper number obtained from the abscissæ is approximately 2. Multiplying the milliampere-seconds for the

former distance by 2 will give the correct number for an exposure at 35 inches.

Fig. 49 is to be used when the distance is to be decreased. Readings are made in much the same manner as for the other chart, except that the start is made at the line 1 on the right side of the figure, the lines of the chart being followed downward and toward the left. For example, if the correct factors be known for a 35-inch

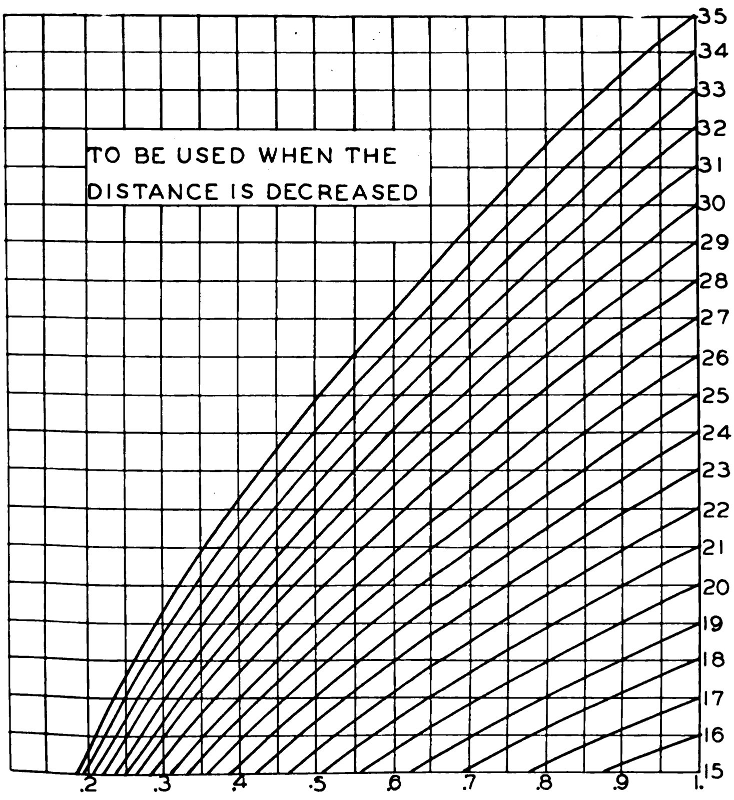

FIG. 49.—A chart from which may be obtained a factor for multiplying the time, milliamperes, or milliampere-seconds of a known x-ray exposure to obtain the correct value when the distance is to be decreased. The factors are the abscissæ, on the bottom of the chart.

distance, following this line of the chart will give approximately 0.75 at 30 inches, 0.5 at 25 inches, and 0.32 at 20 inches. Multiplying the milliampere-seconds known to give a good exposure at 35 inches by either of these factors will give the correct number of milliampere-seconds at the new distance.

Again, if the exposure factors include 100 milliampere-seconds at 35 inches and for any reason it be preferable to make an exposure in one second using 40 milliamperes, beginning at 35 on the line

1 and following the line of the chart, the line will cross the abscissa 0.4 at the ordinate for 22 inches ($100 \times 0.4 = 40$). This shows that the same intensity of exposure will be obtained with 40 milliampere-seconds at 22 inches as with 100 milliampere-seconds at 35 inches.

In most *x*-ray laboratories a few anode-film distances are routinely used, one perhaps more often than any of the others. When this is true, it is easy to memorize the effects that changes from the standard distance to any of the others will have on *x*-ray exposures. When any one of the other distances is used, it is simple to calculate mentally the exposure required by the change from the standard distance.

In our laboratories an anode-film distance of 35 inches is standard (see p. 136). Other distances used are 25, 30, 48, 60, and 72 inches. With 35 as 1, factors for modifying an exposure for the other distances are $\frac{1}{2}$, $\frac{3}{4}$, 2, 3, and 4 respectively. While some of these are not the exact factors, they are so close that exposures modified by them are entirely satisfactory.

In roentgenological work all distances should be accurately measured. In addition to the scale on the tube stand, if a tape measure be fastened to the tube stand, with one end at the level of the tube anode, distance measurements may easily be made. Since errors in distance may cause considerable variations in the density of the films, an accurate distance measurement should be a routine part of each roentgenographic exposure.

Experiment 6.

Object.—To study the effect of voltage on *x*-ray exposures and to prove the law that, other factors remaining constant, the intensity of an *x*-ray exposure, measured photographically, varies as the square of the voltage.

Use a film in an exposure holder as in the preceding experiment. Keep the milliamperes constant at 10 and the distance at 35 inches. Expose the different areas, using the voltages and times given in the following table. Obtain the proper voltmeter settings from the chart prepared in Experiment 3. Be certain to number the film.

Table IX.

Area No	P. K. V.	Time in seconds
1	40	4.0
2	50	2.6
3	60	1.75
4	70	1.3
5	80	1.0
6	40	2.0
7	50	2.0
8	60	2.0
9	70	2.0
10	80	2.0

Develop the film until the lightest area, No. 6, shows some blackening. Rinse, fix, wash, and dry it.

Discussion.—As in the preceding experiments, the first five areas will be of approximately the same degree of blackening, while areas 6 to 10 will increase progressively in density. In exposing the first five areas, the voltage is changed 10 kilovolts for each area, but there is a corresponding decrease in the time to compensate for the increased voltage. The times used have about the same ratio to each other as the numbers 16, 25, 36, 49, and 64, which are the same as the squares of the voltages. If each of these numbers be multiplied by the time of the corresponding exposure, the result will be between 63 and 65, it being impossible to secure measurements of the exact time for these voltages. This part of the experiment shows that the intensity of the exposures does vary directly as the square of the voltages measured in peak kilovolts.

In the last five areas, the time is kept constant so that an increase in the density of the film from area 6 to area 10 would be expected. These densities should have the same ratio as the squares of the voltages used in producing them.

The inverse-square law with reference to anode-film distances holds true for all *x*-ray exposures. For this reason, it is a very valuable law—one that permits of a reference chart being made by calculation only. The law governing variations in intensity produced by variations in voltage is approximately correct for exposures made with plates and films without intensifying screens. When intensifying screens are used, however, the law becomes inoperative. For this reason, when films and screens are used, the preparation of a chart by calculations for reference in roentgenography is impossible.

In roentgenographic exposures the selection of the voltage to be used must be based on the thickness and density of the part being examined and on the quantity of rays, the latter depending on time, milliamperage, and anode-film distance. When using intensifying screens, to shorten the time of an exposure, it usually is preferable to decrease the distance and increase the milliamperage. However, it often is advisable and frequently necessary to shorten an exposure more than can be done by increasing milliamperage and decreasing distance. It then becomes necessary to increase the voltage.

The effects of voltage changes on *x*-ray exposures are influenced by a number of factors. Most important of these is the original voltage—the voltage appropriate for the part to be examined—which is to be increased to permit of a shorter exposure or decreased to give more contrast on the roentgenogram. Voltage changes will have a more pronounced effect if the original voltage be low than

if it be high. This is because a voltage change will add or subtract a greater proportion of shorter wave-length Roentgen-rays from those produced by a lower than from those produced by a higher original voltage (see p. 79). Because of this the addition of a certain voltage to a low original voltage will give a greater effect than if the same amount be added to a higher original voltage.

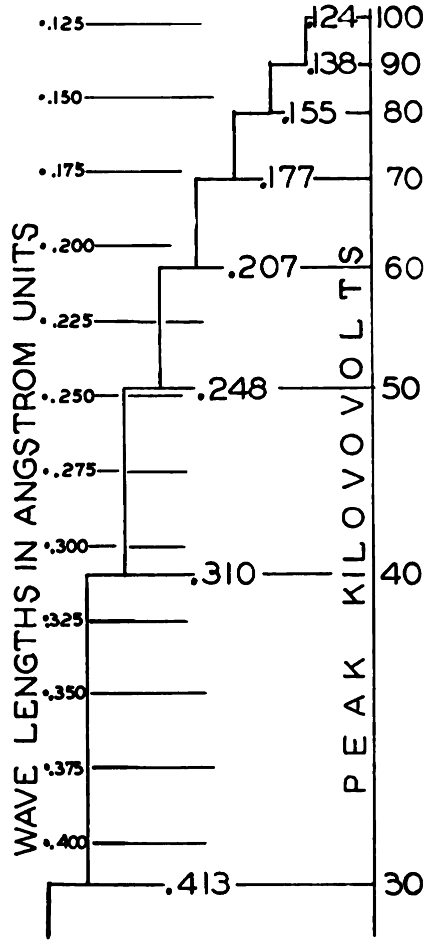

FIG. 50.—Graph showing the effects of the voltage changes on wave-lengths of x-rays. At the left of the graph are wave-lengths in Angström units, in the middle of the graph are given the shortest wave-lengths resulting from the peak kilovoltages given on the right of the graph. The graph shows the progressive decrease in shortest wave-lengths as the voltage is increased in steps of 10 from 30 to 100 peak kilovolts. Compare with Table 1, page 80.

The effects of voltage changes on wave-length is graphically shown in Fig. 50. The data on which this graph is based is given

in Table I, p. 80. The information in the table and the figure is the same, but for emphasis, the graph is included. It is drawn to scale. It shows that the greatest addition of shorter wave-length Roentgen-rays occurs when the voltage is increased from 30 to 40 peak kilovolts. The increase in wave-lengths is less when the voltage is increased from 40 to 50 peak kilovolts, and the addition of shorter wave-lengths from the addition of 10 peak kilovolts

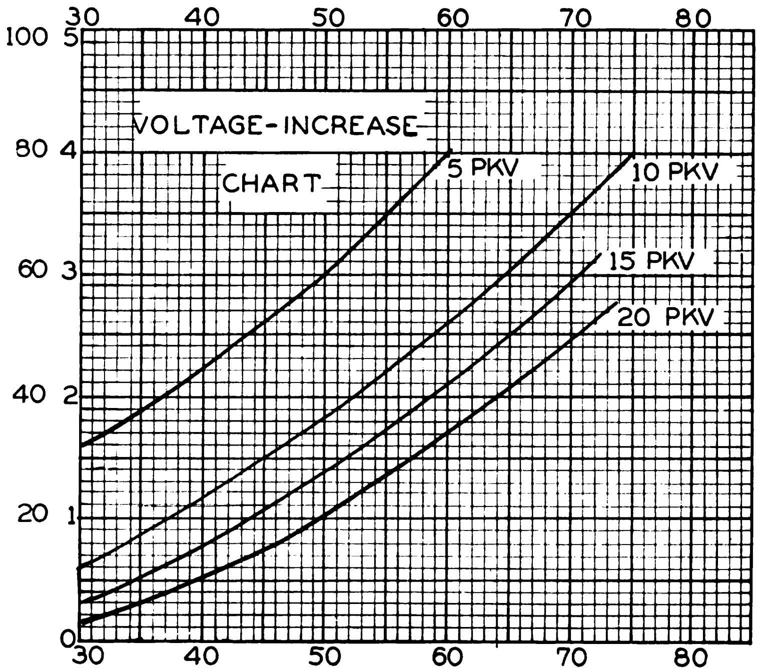

FIG. 51.—A voltage-increase chart. The ordinates at the left of the chart are time in seconds from one to five, and milliamperemeter-seconds from 0 to 100; the abscissæ at the top and bottom of the chart are original voltage values in peak kilovolts. The lines of the chart are for increases of 5, 10, 15 and 20 peak kilovolts. In using this chart read up or down from the voltage value at the top or bottom of the chart to the line for the desired voltage increase. From the point of crossing follow the ordinate to the left of the chart and find the time in seconds or the milliammeter-seconds value for the new exposure. The figures for the milliampere-seconds can also be used as percentages of the original exposure.

steadily decreases as one passes to higher voltages. A study of this table and figure should emphasize the facts that the effects of voltage changes are not constant, and that the starting voltage is most important in determining the effect of any voltage addition or subtraction.

Fig. 51 shows the effects of voltage increases on the times of exposures and on the milliampere-seconds of exposures when intensifying screens and films are used. The basis for this chart is the basic

technique described in Chapter VII. The data from which it was prepared is based on the results of experimental exposures through blocks of paraffin. Both the original voltage and the thickness of the part to be exposed were taken into consideration. In the basic exposure technique a quantity of Roentgen-rays is used represented by 20 milliamperes for five seconds, or by 100 milliampere-seconds, at an anode-film distance of 35 inches, with a voltage appropriate for the thickness of the part being examined and the kind of intensifying screens being used. This chart was designed for use particularly with this technique.

The ordinates at the left of the chart give two values: (1) time in seconds, and (2) milliampere-seconds. It is understood that the time value is always to be used with 20 milliamperes, while the milliampere-seconds may be used with any combination of time and milliamperage that gives the same value. The abscissæ at the bottom and top of the chart give original voltage values in peak kilovolts. There are four lines on the chart, one each to be used with voltage increases of 5, 10, 15 and 20 peak kilovolts. This chart is to be used as follows:

First measure the part being examined and determine its thickness in centimeters. Then refer to the thickness-voltage charts and select the correct voltage for that thickness. The correct voltage will depend on the kind of intensifying screens being used. On the chart follow the abscissa for that voltage until it crosses the appropriate voltage-increase line. From this line follow the ordinate to the left of the chart and select the time in seconds (to be used with 20 milliamperes) or the value in milliampere-seconds. A factor selected in this way will give an exposure of approximately the same density as factors selected from the basic technique.

For example, using Patterson Detail screens with a part that is 13 centimeters thick, the proper voltage selected from the thickness-voltage chart is 50 peak kilovolts (Fig. 52). On the voltage-increase chart (Fig. 51), following the abscissa for 50 peak kilovolts from above downward will give a time value of three seconds for an increase of 5 peak kilovolts, one and four-fifths seconds for 10, one and two-fifths seconds for 15, and one second for an increase of 20 peak kilovolts. The corresponding milliamperage-seconds values will be 60, 36, 28, and 20 respectively.

If the part be 20 centimeters thick and Eastman Hi-definition screens be used, the proper voltage from the thickness-voltage chart (Fig. 52) will be 58 peak kilovolts. Following the abscissa for 58 peak kilovolts on the voltage-increase chart will give a time value of three and nine-tenths seconds for an increase of 5 peak kilovolts, two and two-fifths seconds for 10, one and nine-tenths seconds for

15, and one and a half seconds for an increase of 20 peak kilovolts. The corresponding milliampere-seconds will be 78, 48, 38, and 30 respectively.

As long as the voltage to be increased is based on previous thickness-voltage determinations, it has been found experimentally that the voltage-increase chart (Fig. 51) can be used to increase voltage and at the same time indicate correct modifications of the other factors (time and milliamperes) that were used in the thickness-voltage determinations. In using the chart for this purpose the milliampere-seconds values (from 0 to 100) given in the ordinates on the left of the chart will also give the percentage of the original milliampere-seconds that should be used for exposures after the voltage has been increased.

As an example the distance of the basic technique may be reduced from 35 to 25 inches. This will permit a reduction from 100 to 50 in the milliampere-seconds of the exposure (Fig. 49). At this distance voltage may be added and a new value for milliampere-seconds be obtained from the chart. If the original voltage be 40 peak kilovolts and the increase is to be 10 peak kilovolts, following the abscissa for 40 to the point of crossing with the line for an increase of 10 peak kilovolts, the corresponding ordinate (from the milliampere-second column at the left of the chart) will be 21.5. Using this as a percentage, the exposure will be correct if 21.5 per cent of 50 or 10.75 milliampere-seconds be used. This may be adequately approximated by 40 milliamperes for a fourth of a second.

As a second example, if the original voltage be 50 peak kilovolts and one wishes to make as short an exposure as possible and the capacity of the tube be 100 milliamperes, after 20 peak kilovolts have been added the percentage value will be 20. Twenty per cent of 100 will be 20, which at 100 milliamperes will give an exposure time of a fifth of a second. By reducing the distance from 35 to 25 inches this may be halved and an exposure time of a tenth of a second be used.

This chart shows the importance of voltage as one of the factors in roentgenographic exposures. Slight errors in time or milliamperage will have little effect on films, while similar errors in voltage will have a more pronounced effect. From the chart it may be seen that using a voltage that is 5 peak kilovolts too high will cause an overexposure of from 20 to 70 per cent. Fortunately there is a latitude in films which allows of some under- or overexposure in films of good quality. Nevertheless these facts make the selection of the proper voltage the most important part of each roentgenographic exposure.

Dark-room manipulation possibly excepted, the mistake most

often made in roentgenography is overexposure from the use of voltages that are too high resulting in rays that are too penetrating, to compensate for which the films are underdeveloped with a consequent lack of both contrast and detail. Since this is true, too much emphasis cannot be put on the voltage determinations in Experiments 1 and 3 nor upon the careful selection of the proper voltage for each exposure.

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CHAPTER VII.

A BASIC ROENTGENOGRAPHIC TECHNIQUE.

In laboratory procedures an attempt should be made to reduce to a routine all work that is done. By repetition many of the details tend to become reflex or automatic, leaving the mind free to think of those which cannot be included. Whenever it can be accomplished, it also is advisable to establish some basic method or foundation, from which, by changes in the different factors, all other procedures may be derived. Roentgenographic work can be reduced to a routine and readily permits of the adoption of a basic or fundamental method of making x-ray exposures. These phases of the subject will be discussed in this chapter.

In this discussion all of the components which enter into roentgenographic exposures must be included. These are:

1. The photographic material used.
2. The distance from the anode of the tube to the film.
3. The milliamperes of current through the tube.
4. The time of the exposure.
5. The voltage of the current applied to the tube.
6. The part of the body being examined, especially its thickness and roentgenographic density.

Of these, the distance, time, milliamperage, and voltage constitute the exposure factors—the distance, time, and milliamperage governing the quantity and the voltage controlling the quality or penetrability of the Roentgen-rays used.

Of primary importance in this discussion is a decision as to the type of routine practice that should be adopted. It is obvious that one in which there is the least variation in the exposure factors would be preferable to any other. The many different kinds of roentgenographic exposures make it impossible to select one factor and vary it, keeping the others constant, so that the best procedure would be to select one as the chief variable factor and change it more often than any of the others. Since it is the differences in thickness and roentgenographic density of the parts of the body requiring examination that necessitates variations in exposures, it would seem that the factor most nearly compensating for these differences should be selected as the one to be most often varied. Inasmuch as the voltage governs the penetrability of the rays—long rays of low penetrating power produced by a low voltage for thin parts, and shorter, more penetrating rays produced by a higher voltage for thick or dense

parts—in a basic roentgenographic technique the voltage should be the chief variable factor.

With the voltage to be varied according to the thickness and density of the part being examined, what values may be given the other exposure factors and what photographic material is to be selected for a basic roentgenographic exposure technique?

Two kinds of photographic material are available for use, films without screens and films with double intensifying screens. Films without screens, particularly those especially manufactured for non-screen use, are suited for examinations of the extremities, parts with thicknesses not exceeding 12 to 14 centimeters. For all other examinations films and screens are preferable. Using them, exposures can be made with a much smaller quantity of rays; more contrast can be obtained than with films alone, they are especially adapted to rapid exposures, and they make possible the use of a Potter-Bucky diaphragm or a wafer grid. It will be shown later that the basic technique here proposed will include, where preferable, the exposure of films without screens and the exposures with different kinds of intensifying screens.

Less distortion and better detail can be secured with the longest practicable anode-film distance. At the longer distances the rays do not diverge so much between the structures being examined and the film, thus making the images more nearly the exact size and shape of the structures themselves. Also, at the longer distances the focal spot of the tube, compared to the film surface, approaches more nearly a point, thus increasing detail on the films. Since most tube stands are made to permit elevating the tube anode from 35 to 40 inches above the top of the table, 35 inches seems a suitable distance to select.

There are a number of different combinations of milliamperage and exposure time that could be selected. From these, 20 milliamperes of current through the tube and a five-second exposure time have been chosen. Twenty milliamperes is within the capacity of nearly all hot-cathode x-ray tubes. Five seconds is not too long to be tiresome to the patient; it is long enough to permit necessary corrections in tube current; it is within the capacity of all timing devices, and it may be accurately measured without a timer. The milliamperage and time combined as milliampere-seconds represent a relatively large quantity of rays with which a voltage may be used sufficiently low to give considerable contrast on the films. A milliampere-seconds value of 100 gives a number with which calculations of exposures derived from the basic technique can be made more easily than with any other.

In a basic roentgenographic method of this sort, with the other

three factors constant, the penetrability or quality of the rays (governed by the voltage of the current applied to the tube), is to be the chief variable factor, the variations in the voltage being determined by the thicknesses and densities of the parts of the body being examined. Thicknesses of parts of the body, from a minimum of 1 centimeter in the fingers and toes to a maximum of 35 centimeters through the lumbosacral region in a lateral direction, are encountered. The measurement of the thicknesses of the parts, either with a ruler or a pelvimeter, or a special measuring apparatus, should present no difficulties.

The measurements usually should be made through the thickest portion of the part to be examined. For example through the patella for an antero-posterior exposure of the knee and through the middle portion of the abdomen for most of the abdominal structures. Since a change in posture, the application of compression bands, etc., may cause a considerable change in thickness, measurements usually should be made after the patient is in position for the exposure. Also they should be made in the direction traversed by the central rays from the tube. This is especially important when exposing oblique views such as those of the mandible, mastoids, or nasal accessory sinuses.

The roentgenographic density of parts of the body, by which is meant their ability to absorb Roentgen-rays, is variable. As a general statement it may be said that three kinds of roentgenographic density are encountered. These include what may be called average density—that of the abdomen, pelvis, hips, shoulders, neck, and extremities; the density of the thorax through the lungs, and the density of the structures of the head and skull. Except the lungs and head, all parts of the body are of virtually the same density. Slight variations do exist. The extremities of a muscular person may be slightly more dense than those of the same thickness of a fat person; the density of the tissues of a child is less than that of an adult; the density of the upper part of the abdomen through the liver is greater than that of the middle portion; while most marked is the diminished density of the tissues produced by atrophy from disuse and that due to age. However, in selecting exposure factors for a basic technique, it may be stated, that, except for the lungs and skull, rays of a quality suitable for a certain thickness of tissue will be appropriate for that thickness wherever it may be found, taking as a basis the average density of tissues of healthy adults. Therefore, using a quantity of rays represented by 100 milliampere-seconds at a 35-inch anode-film distance, a basic roentgenographic technique may be completed by selecting a suitable voltage, giving rays of appropriate quality for each thick-

ness of tissue encountered, stopping, of course, when the highest voltage permitted by the tube has been reached.

The determination of the relationship between voltage and thicknesses of tissue of average density is the most important part of the development of a basic roentgenographic technique. This may be done by trial exposures—making several exposures with different voltages through a part of the body of a certain thickness, developing the films for the full time at the proper temperature, and selecting the voltage that gives a good result. This is time consuming, requires the use of considerable material, and, what is more important, necessitates multiple exposures either of the same or of different persons. It may be done by charting the results of diagnostic exposures as explained on page 186. Exposures through some substance that has the same absorbing power for Roentgen-rays as human tissue of average density would be much simpler and would answer the purpose quite as well. Paraffin has this property, so that paraffin blocks of different thicknesses may be used to determine experimentally the thickness-voltage relationship for a basic roentgenographic technique.

The results of experiments of this kind, showing the relationship between thickness and voltage, have been incorporated in a chart, called a thickness-voltage chart, which is shown in Fig. 52.

When originally designed, there was but one speed of intensifying screen in common use and special non-screen films had not been produced. Hence, the chart was simple with but one voltage-thickness line on it. Since then there have been important changes in x-ray films and in intensifying screens. As new materials have appeared, changes in the thickness-voltage chart have been made permitting the continuous use of this basic technique and the technique derived from it.

The thickness-voltage chart now represented in Fig. 52 is somewhat complex. It is divided into two parts. In the upper part of the chart there are five lines, one for each of the three types of screens manufactured by the Eastman Kodak Company and two for non-screen films. One of the latter is for special non-screen films; the other for ordinary films exposed without screens. In the lower part of the chart there are six lines, one for each type of screen manufactured by the Patterson Screen Company and, as in the upper part, two for non-screen films. Some difficulty was experienced in modernizing the lower part of this chart. The Patterson Screen Company has ceased the manufacture of Hi-speed intensifying screens and has gradually increased the speed of the Par-speed screens. Two reasonably new Patterson screens that had not been used, one Hi-speed and one Par-speed, that were recently tested

were exactly alike in their speed. For these reasons the line on the chart for Par-speed screens is based on tests conducted with an older Par-speed screen that has had some use. The line given for the Hi-speed screens may be used with newer Par-speed screens.

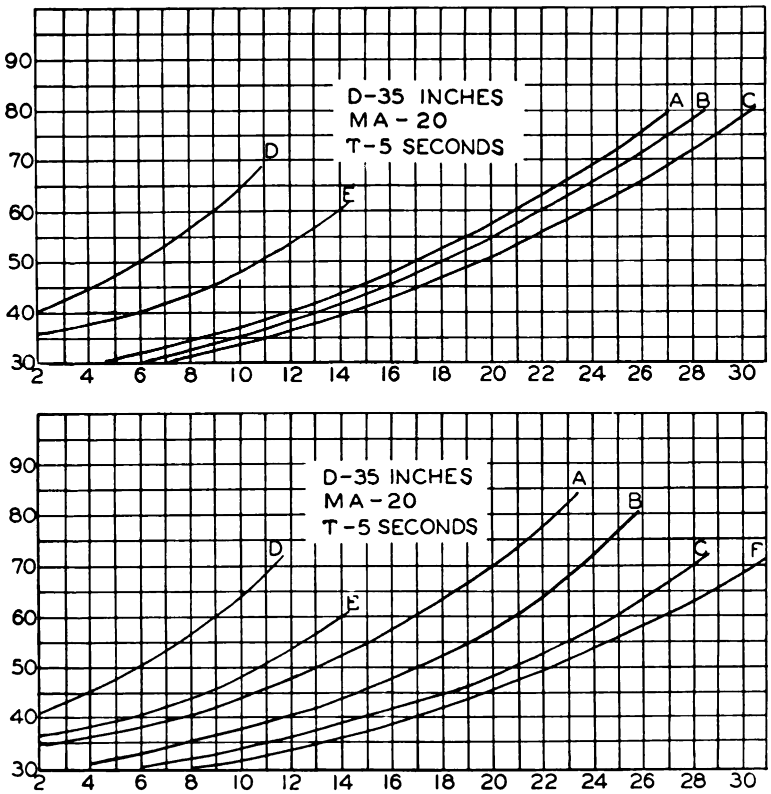

FIG. 52.—The thickness-voltage chart. The ordinates are voltage values in peak-kilovolts; the abscissæ are thicknesses of parts of the body in centimeters. The top half of the chart is for use with intensifying screens manufactured by the Eastman Kodak Company. There are 5 lines on the chart: A, for use with High-Definition Screens; B, for use with Fine-Grain Screens; C, for use with Ultra-Speed Screens; D, for use with ordinary films as a non-screen exposure; E, for use with special non-screen films.

The bottom half of the chart is for use with screens manufactured by the Patterson Screen Company. There are 6 lines on the chart. A, for use with Detail Screens; B, for use with older Par-Speed Screens; C, for use with Hi-Speed Screens; D, for use with ordinary films in non-screen exposure; E, for use with special non-screen films; and F, for use with Fluorazure Screens.

On this chart no attempt is made to distinguish the different kinds of x-ray films in common use. Experimental exposures through paraffin blocks and everyday use of the different films did not disclose any essential differences in them. This applies to exposures without screens of both ordinary and special non-screen films; for

this reason the lines on the two parts of the chart for exposures without screens are the same.

In the experiments on which this chart is based, a constant distance, milliamperage, and time were employed, using those selected as being most appropriate for a basic technique. The voltage determinations were made with a sphere gap, and, to eliminate errors from fluctuations, were carefully checked during the experiments. The films were developed in fresh developer for full time at the proper temperature.

The ordinates of the thickness-voltage chart are the voltage values expressed in peak kilovolts; voltage values as spark gap in centimeters or in inches may be used. The voltage values extend from 30 to 90 peak kilovolts, corresponding closely to a spark-gap range of 2 to 5½ inches.

The abscissæ of the chart represent thicknesses of tissue from 2 to 30 centimeters. For the thinner parts, if 30 peak kilovolts with screens give overexposed films, or if a voltage as low as this cannot be obtained from the machine, the time of the exposure may be shortened or films without screens may be used.

The antero-posterior thickness of the body rarely exceeds 26 to 28 centimeters. Should a person be encountered thicker than this, by the use of compression the total thickness traversed by the rays can be reduced to within the limits of the chart. The transverse or lateral thickness of the abdomen and pelvis often exceeds 28 centimeters which requires the use of a relatively high voltage and an increase in the time of the exposure. Since films of these parts of the body always are taken with a Potter-Bucky diaphragm, exposures of them will be considered when diaphragm exposures are discussed.

In many *x*-ray laboratories a thickness-voltage chart as elaborate as the one in Fig. 52 will not be needed. Only those lines on the chart suited to the kinds of intensifying screens in the equipment and those of such exposures as are made without screens need be included. For instance, if all the screens are alike and a single kind of non-screen exposure material is used, only two lines are necessary on the chart, one for exposures with intensifying screens and one for non-screen exposures. If a table instead of a chart be more desirable, the voltage and thickness values may be obtained from the chart and made into a suitable table that can be used in the same way as the chart.

In using a thickness-voltage chart of this kind, the thickness of the part is first measured in centimeters. Then the line (abscissa) for that thickness at the bottom of the chart is followed upward until it crosses the line for the kind of intensifying screen being used,

or until it crosses the line for the non-screen material in use. From the point of crossing, the horizontal line is followed to the left margin and the proper voltage is selected for that thickness from the ordinates at the left of the chart. With this voltage, and other factors suggested for this basic technique or some modification of them, the exposure should be made.

In the thickness-voltage chart the voltage given for each tissue thickness is the average that should be used with that particular thickness. Since the percentage of error caused by using a voltage that is very slightly too high is about the same as that for one that is the same amount too low, should the exact voltage for a certain thickness not be obtainable on the machine, other factors must determine the voltage to be used. For instance, if the patient be a healthy muscular adult and the film being made is to show bone structures, the next higher voltage should be used; if the patient be young, feeble, has been ill for some time, or the soft tissue rather than the bone be desired, then the next lower voltage should be used.

As discussed in the preceding paragraphs, a basic roentgenographic technique may be devised by adopting double-coated films and double intensifying screens as photographic material, an anode-film distance of 35 inches, 20 milliamperes of current for five seconds time, with the voltage varied according to the thickness of the part being examined, and determined before the exposure from a chart prepared for that purpose. Not only can the voltage appropriate for the thickness of the part be selected, but the voltage chosen may also be suited to the type of intensifying screens being used. This technique is simple; it has one chief variable factor, and it allows of the selection of the factors before exposures with such a degree of accuracy that the results can be predicted. It depends on the thickness and relative density of the part being examined and not on the size or weight of the patient. As will be shown in a following chapter, by necessary modifications of the different exposure factors in this basic technique according to the laws which govern x-ray exposures, almost all roentgenographic technique can be derived from it.

Experience leads to the belief that the thickness-voltage chart given in Fig. 52 will be found correct for most installations. This statement presumes that the machines have been calibrated in a manner similar to that given in Experiments 1 and 3 with a sphere gap corrected for altitude or with a point gap at not too high an altitude; that intensifying screens are of the same speed as those used in making the chart; that the machines with which it is used have enough voltage intervals in the secondary circuit to make the

voltage the chief variable factor; and that the supply-line current, transformer design, rectifier, measuring instruments, tube, etc., are such that the Roentgen-ray output for the various voltages and milliamperages, both in quantity and quality, is the same as that of the machine used in making the chart and of those with which it has been successfully used.

To become familiar with the use of the thickness-voltage chart and the basic roentgenographic technique as here advocated, study the chapter on "Combinations of Exposure Factors." In this chapter are given the modifications of the basic technique that have been found necessary for exposing films of different regions of the body under the varying conditions that exist when such exposures must be made. Except in a few instances in which it is not applicable, the thickness-voltage chart is used throughout.

To test the chart, make exposures of different regions of the body, using the technique advocated for each particular part. Measure the thickness of the part to be examined with a centimeter ruler, with the centimeter scale on a pelvimeter, or with a special measuring device, and select the voltage for that thickness from the line on the chart for the intensifying screens being used. In making these trial exposures care must be exercised in the selection of the voltage. Calibration charts like those described in Experiments 1 and 3 or some similar method of voltage selection should be used. When changing the milliamperage, especial care must be taken to compensate for the changes that will occur in the voltage. Inasmuch as this technique is based on the standard development of films, any deviation will give poor results.

If a study of the finished films shows them to be of poor quality, it may be possible to modify the thickness-voltage chart so that it will apply. This can be done by moving the thickness-voltage line upward or downward depending on whether the films are under- or overexposed, upward if the test films be too pale and downward if they be too dense. It is probable that the curvature of the line will not need changing. If this does not suffice, then a set of paraffin blocks should be prepared, the Advanced Experiments performed as outlined in Chapter VIII, and a thickness-voltage chart prepared. If this be done, the chart will be correct for that particular installation with its own accessories and operating under its own peculiar conditions. Under any circumstances, this procedure is preferable.

Unfortunately the basic technique as outlined in the preceding pages is not applicable to some machines. Those for which it is not suited include those having large steps in the secondary voltage, those in which the introduction of the rheostat to secure such steps causes so much irregularity in the secondary voltage that better

results can be obtained without it, and, as a general rule, many unit type machines used for roentgenography. For these, the same advantages follow the use of a routine procedure and a basic technique, but a different technique, based on the same general principles, must be devised.

If the construction of the control devices in the primary circuit be such that the required number of voltage steps cannot be obtained to make the voltage the chief variable factor, then a second factor must be selected to be varied with the voltage. This second variable factor should be the time of the exposures. A basic technique with two variable factors, the voltage and the time, may be devised in much the same manner as one in which the voltage is the only variable factor, and the results incorporated in an exposure chart. A chart of this kind is shown in Fig. 53.

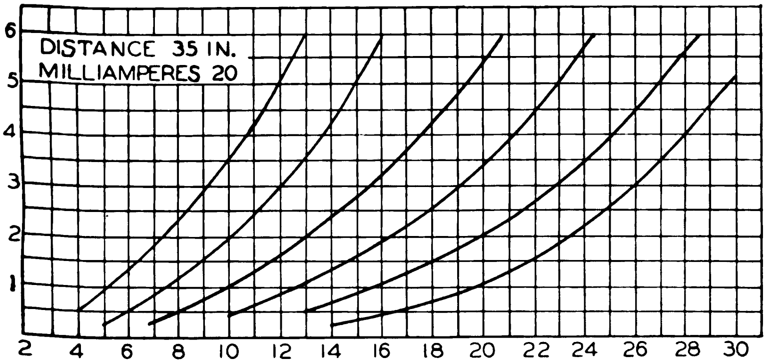

FIG. 53.—An exposure chart made by experimental exposures through paraffin blocks for an x-ray machine with six voltage selections, the chart showing a curve for each voltage. The ordinates are exposure times in seconds; the abscissæ are thicknesses of parts in centimeters. The constant factors are an anode-film distance of 35 inches and 20 milliamperes. This chart was made to be used with high speed intensifying screens.

The machine for which this chart was made has an autotransformer with 20 steps and a 15-step rheostat, with only 6 of the autotransformer steps giving voltages within the range of those useful in roentgenography. With 20 milliamperes, on button 1 the peak kilovoltage is 50; on button 6 it is 94, there being steps of approximately 8 kilovolts between buttons. An attempt to use smaller steps by the use of the rheostat caused so many irregularities in the secondary voltage that the attempt was abandoned and a different basic technique devised for this machine. With it there is also a lower Roentgen-ray output than with any other machine of similar type that has been tested. A voltage of 84 peak kilovolts is required, the other factors being constant, to give the same Roentgen-

ray output produced by 70 kilovolts on other machines. Although having operating characteristics differing from others, a special basic technique was devised for this machine and, by means of experimental exposures through paraffin blocks, the chart in Fig. 53 was made. The use of this technique and this chart on this machine gives good results.

Other combinations than the one recommended, with different constant and variable factors, may be used with equal success in a basic technique as long as the principles underlying the method of selecting and using the combinations are observed. For example, the use of a 10-milliampere small spot tube has been recommended for roentgenography of all parts permitting of immobilization and a long exposure time. Because of the small focal spot, better detail can be secured than by the use of any other tube. Its use, however, necessitates two sets of exposure factors with different variables. In one, especially for films of the extremities, the milliamperes, time, and distance may be kept constant and the voltage varied according to thickness. For thicker parts, such as the vertebral column and pelvis, limiting the exposure time to five seconds might require a voltage higher than that permitted by the tube. This would necessitate a second set of exposure factors, especially for thick parts, in which the voltage, milliamperage, and distance are the constant factors with the exposure time varied to suit the thickness.

Exposure charts for a technique of this kind can easily be made. For the first set of factors a thickness-voltage chart can be prepared; for the second set a chart can be made using 10 milliamperes, a voltage nearly as high as the tube permits, and a constant distance, with the time of the exposure varied to suit the thickness of the part to be examined (see Figs. 53 and 57). These charts can be made by experimental exposures through blocks of paraffin according to the methods given in Chapter VIII.

The kinds of technique and exposure charts that can be used with unit type machines are discussed in Chapter X.

In this chapter have been introduced the ideas of adopting a basic method of making roentgenographic exposures and of developing charts from which the proper factors for each roentgenographic exposure may be obtained. These are based on the thickness and density of the parts of the body to be examined and not on the size or weight of individual patients. One basic technique is given in detail, from which, as will be given later, by modifications of the various factors, practically all roentgenographic technique may be derived. It is believed that this type of technique is fundamentally

sound and that, by its adoption and use, better results can be obtained than by the use of any other method.

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CHAPTER VIII.

ADVANCED EXPERIMENTS.

THE objects of the introductory experiments were to study the electric currents of an x-ray machine and the laws of roentgenographic exposures and to teach familiarity with the details of the operation of an x-ray equipment. The objects of the advanced experiments are to present a method of photographically measuring the Roentgen-ray output of an x-ray equipment, to make a determination of the relationship between thickness and voltage, and to prepare a thickness-voltage chart like that given in the preceding chapter. There will also be included general instructions for making experimental exposures through paraffin blocks to determine the exposure factors in a basic technique for equipments with which a thickness-voltage chart cannot be used.

PARAFFIN BLOCKS.

It has been found that paraffin has about the same absorbing power for Roentgen-rays as human tissue of parts of the body other than the skull and the thorax through the lungs. The absorbing power is not exactly the same, that of paraffin being slightly less than that of human tissue. They are so nearly alike, however, that a set of roentgenographic exposure factors that will give an image on a photographic emulsion of slightly greater than average density (see page 137) through a given thickness of paraffin will give an image of average density through most parts of the human body of the same thickness.

For this reason exposures through blocks of paraffin may be used experimentally to duplicate actual working conditions in an x-ray laboratory. By their use almost any roentgenographic problem may be experimentally worked out. Paraffin blocks have been used in testing the speed of intensifying screens, in determining the absorption of the grids of Potter-Bucky diaphragms, in examining new photographic materials, and in teaching students and technicians. Of greater importance is their use in measuring the Roentgen-ray output of machines, in determining sets of exposure factors, and in devising exposure techniques that can be used as a basis for practical roentgenography. Because of their usefulness, a set of paraffin blocks is a very valuable addition to any laboratory.

Our first experiments were made with ordinary commercial

paraffin in blocks 1.6 centimeters thick, as it comes in pound packages from the grocer. A set of thirty-five blocks each 1 centimeter thick were next made which melted into a shapeless mass during the first hot weather. The set now in use was made of paraffin of a high melting point bought from a laboratory supply house. It consists of two blocks that are 10 centimeters thick, one that is 5 centimeters thick, two that are 2 centimeters thick, and six that are 1 centimeter thick (Fig. 54). With this set any thickness from 2 to 35 centimeters can be secured. It has been in use for some time at all seasons of the year and has proved entirely satisfactory.

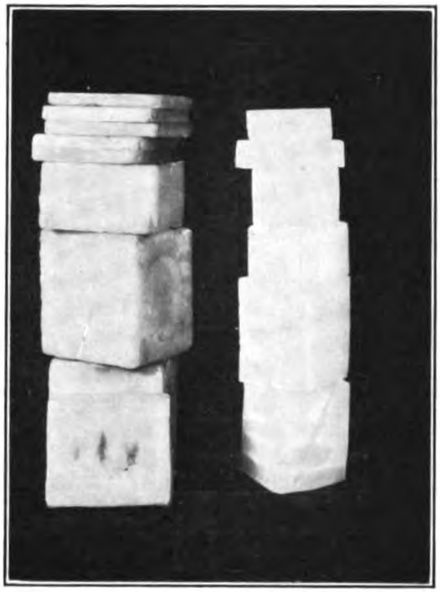

FIG. 54.—Two sets of paraffin blocks as described in the text. In the larger set the 2-cm. block containing the teeth is standing on edge at the bottom of the pile.

A set of blocks for temporary use can be made easily and quickly from commercial paraffin. A permanent set, however, should be made of paraffin with a higher melting point. For the former, 3 pounds are required. It is sold in packages, in blocks 13 centimeters long, 6.5 centimeters wide, and 1.6 centimeters thick, four blocks to the pound, or twelve blocks in 3 pounds. Each of these should be cut into halves transversely through the middle of the blocks. Two blocks each 8 centimeters thick should be made from ten of these smaller pieces. This can be done by passing the blocks through a flame until the surface is melted and then pressing them together. Four other blocks will be required, two that are 2 centimeters thick and two that are 4 centimeters thick. The former may be made by sticking two of the pieces together and shaving off the paraffin to the desired thickness; the latter by sticking three of the blocks together and shaving off one side until the desired thickness is reached. If two pieces of heavy cardboard, as wide as the thickness of the blocks, be stuck to the sides and used as guides, the shaving off of the blocks to the desired thickness can be done accurately. A set of blocks of this kind will give any thickness, from 2 to 28

centimeters, in steps of 2 centimeters. To cast an image on the film when used, three teeth should be put into one of the 2-centimeter blocks (see page 149). When not in use, if stored in a refrigerator, paraffin blocks of this kind can be kept indefinitely.

In making a permanent set of blocks from paraffin of a higher melting point, a simple mold like the one illustrated in Fig. 55 may be used. This consists of a framework (F) of ½-inch boards, 2½ to 3 inches in height. The mold proper is made of two cleaned 5- by 7-inch photographic plates (P) which form its sides, the partitions being made of cleaned lantern slide plates (LS), held apart by wooden separators (S), which are as wide as the desired thickness of the blocks. The mold is held together by three square wedges

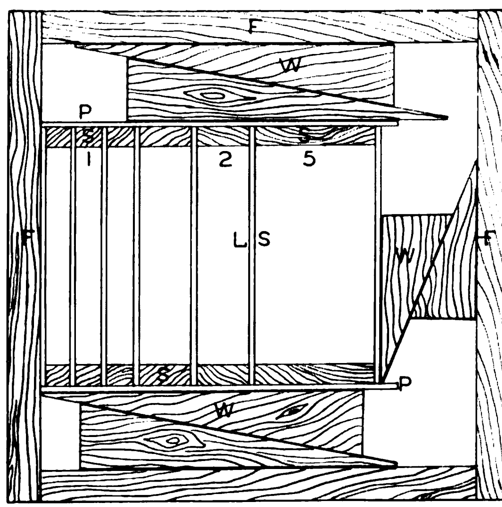

FIG. 55.—Vertical view of a simple collapsible mold for making paraffin blocks by the method described in the text.

(W) and rests on an 8- by 10-inch cleaned photographic plate. To prevent the paraffin from sticking, the glass parts of the mold should be rubbed with motor oil or petrolatum before it is assembled.

The paraffin is heated in a suitable container until it is melted. Before it is poured into the mold, it is allowed to cool to a temperature just above the melting point. This cooling is important, for very hot paraffin will run through the cracks of the mold, and the contraction resulting from its cooling will cause large defects in the blocks. When the paraffin has solidified, the mold is broken apart and the blocks removed. Minor defects may be filled in by pouring melted paraffin into them and smoothing the surface with a heated glass plate.

To produce an image, two or three teeth should be put into one

of the 2-centimeter blocks. A single, a double, and a three-rooted tooth, each containing defects and fillings to produce detail in their images on the films, have been found satisfactory (Fig. 56). Holes slightly larger than the teeth should be cut in the block, the teeth placed in them, and the holes filled with melted paraffin. The two kinds of sets of paraffin blocks, the manufacture of which has been described, are shown in Fig. 54.

In all experimental exposures, the block containing the teeth should be placed nearest the film.

Recently the results of experimental exposures through paraffin blocks have been evaluated by the use of a Weston exposure meter, model 715. This method of determining the density of exposed areas has been found somewhat more accurate than judging by sight. In using an exposure meter it was necessary to make a new set of blocks from which the teeth were omitted. However, the results of the experiments have not shown any marked or important variations.

In the experiments which follow, detailed instructions are given for performing the experimental exposures necessary in making a thickness-voltage chart. These especially are intended for all machines for which a suitable calibration chart has been prepared (Experiments 1 and 3), for machines on which the autotransformer settings give accurate secondary voltages, and for unit type machines with voltage intervals as small as 2 or 3 peak kilovolts in the secondary circuit. Of course, the voltage capacity of the tube should not be exceeded.

EXPERIMENTS 7, 8, AND 9.

Object.—To determine the paraffin thicknesses giving optimum exposures with certain voltages.

Unfortunately the exact details of these experiments cannot be given. This is because there is so much difference in the construction of x-ray machines and in the speed of intensifying screens. The minimum voltage on different machines varies from 30 peak kilovolts to as much as 50 or more. Intensifying screens probably can be grouped in three general classes, slow-speed, par- or medium-speed, and high-speed screens, with a fourth screen much faster than the others known as the "Flurazure" screen.

In performing the first of these experiments (No. 7), use a double-coated film in either a 6½- by 8½- or an 8- by 10-inch cassette fitted with good double intensifying screens. With a wax pencil mark off the face of the cassette into 10 areas, similar to the film exposure holder used in the earlier experiments. Number these areas from 1 to 10. The constant exposure factors are those selected as most

appropriate for a basic technique. Those suggested are an anode-film distance of 35 inches, a milliamperage of 20, and a five-second exposure time. These should be kept constant throughout this and the following experiments. Do not fail to number the film with a lead number at the time of the exposure; it also is advisable to number at least two of the areas. In a suitable notebook or on a filing card keep a careful record of the voltages and paraffin thicknesses used.

The voltages and paraffin thicknesses must be selected from those given in Table X as most appropriate for the intensifying screens used and the voltage selections that are available. Table X gives three columns of voltages and paraffin thicknesses appropriate for three general classes of intensifying screens. Five paraffin thicknesses are given under each voltage, numbered from 1 to 5. For Experiment 7 select the group of paraffin thicknesses corresponding to the lowest peak kilovoltage given by the machine in the column for the kind of intensifying screens used. Using these, expose the first five areas on the film. Expose the areas from 6 to 10 on the film using the group of five paraffin thicknesses given for the next higher voltage.

When the exposures have been completed, carefully develop the film. This should be done in a safe dark room, with fresh developer at the time and temperature recommended as optimum for that developer, regardless of the appearance of the images on the film. Following development, the film should be rinsed, thoroughly fixed, and carefully washed and dried. There should be no variation from this standard dark-room procedure, for doing so will detract from the quality of the film. The finished film will look like the one shown in Fig. 56.

When the film is dry, put it in a good illuminator and study it carefully. Examine all of the images with particular attention to density, detail, and contrast (see Chapter IX). If each group of five areas varies in density from one that is too dense at the top to one that is not dense enough at the bottom, the film is satisfactory. From the film select a paraffin thickness giving an image slightly denser than would be considered best for both voltages. These thicknesses need not be exactly represented on the film, but may be an uneven number of centimeters of thickness, intermediate between two areas on the film. When the selections have been made, they will represent the thicknesses of paraffin in centimeters most appropriate for the quality of Roentgen-rays produced by these two voltages. Inasmuch as these selections will be used later in making a thickness-voltage chart, the selections should be recorded and the film carefully preserved.

TABLE X.

Slow speed or detail screens.		Par-speed screens.		High speed screens.	
Area No.	Paraffin thickness, cm.	Area No.	Paraffin thickness, cm.	Area No.	Paraffin thickness, cm.
30 P.K.V.		30 P.K.V.		30 P.K.V.	
1	2	1	2	1	2
2	4	2	4	2	4
3	6	3	6	3	6
4	8	4	8	4	8
5	10	5	10	5	10
40 P.K.V.		40 P.K.V.		40 P.K.V.	
1	4	1	6	1	8
2	6	2	8	2	10
3	8	3	10	3	12
4	10	4	12	4	14
5	12	5	14	5	16
50 P.K.V.		50 P.K.V.		50 P.K.V.	
1	8	1	12	1	14
2	10	2	14	2	16
3	12	3	16	3	18
4	14	4	18	4	20
5	16	5	20	5	22
60 P.K.V.		60 P.K.V.		60 P.K.V.	
1	12	1	14	1	18
2	14	2	16	2	20
3	16	3	18	3	22
4	18	4	20	4	24
5	20	5	22	5	26
70 P.K.V.		70 P.K.V.		70 P.K.V.	
1	14	1	18	1	20
2	16	2	20	2	22
3	18	3	22	3	24
4	20	4	24	4	26
5	22	5	26	5	28
80 P.K.V.		80 P.K.V.		80 P.K.V.	
1	18	1	20	1	22
2	20	2	22	2	24
3	22	3	24	3	26
4	24	4	26	4	28
5	26	5	28	5	30
90 P.K.V.		90 P.K.V.		90 P.K.V.	
1	20	1	22		
2	22	2	24		
3	24	3	26		
4	26	4	28		
5	28	5	30		

TABLE X.—Paraffin thicknesses appropriate for different peak kilovolts with three classes of intensifying screens. These are to be used in the performance of Experiments, 7, 8, and 9.

Experiment 8 should be performed in a similar manner using the next higher voltage interval on the machine for the first five areas and paraffin thicknesses, and the second higher voltage with its appropriate paraffin thicknesses. This film should be carefully developed, and the selection of the appropriate thicknesses of paraffin for the two voltages carefully made.

Experiment 9 is similar to Experiments 7 and 8, except that two higher voltages are used with its group of five appropriate paraffin thicknesses. Do not exceed the voltage capacity of the tube. In selecting the appropriate thicknesses of paraffin from this film, and possibly also from the one exposed in Experiment 8, it must be remembered that contrast on these films will not be as good as on the one exposed in Experiment 7. This is because the greater paraffin thicknesses and higher voltages will give much more scattered radiation than on the first film with consequent loss of contrast and obscuring of detail.

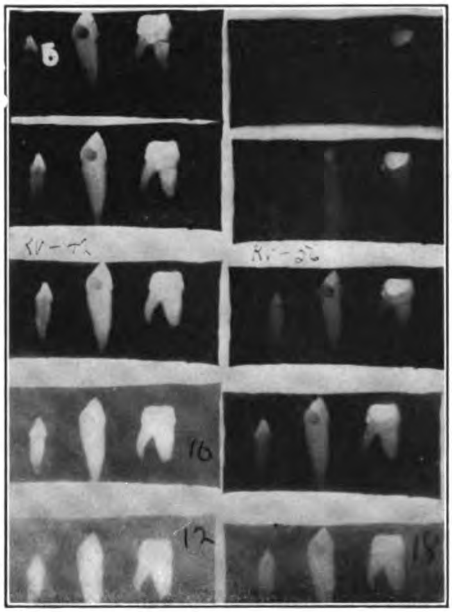

FIG. 56.—A reproduction of a film used in experimental exposures through paraffin blocks.

THE PREPARATION OF THE THICKNESS-VOLTAGE CHART.

In Experiments 7, 8, and 9, a number of thicknesses of paraffin have been selected as most appropriate for a number of voltages, increasing from a low voltage in regular intervals to a voltage near the maximum permitted by the tube. The quantity of rays has been kept constant at that represented by 100 milliampere-seconds at a 35-inch anode-film distance. These findings should now be incorporated in a thickness-voltage chart.

Beginning at the lower left-hand corner on a piece of cross-section paper, number the abscissæ along the bottom in centimeters from 4 to the number selected from Experiment 9. Number the

ordinates along the left margin in the different voltage values, as in Fig. 52. On the paper, place a dot where the ordinates and abscissæ for the various voltages and paraffin thicknesses selected during the experiments cross each other. Connect these dots by an irregular curve and a preliminary thickness-voltage chart is completed.

In Experiments 7, 8, and 9 only one type of intensifying screen has been used. If more than one kind of screen be in use, the experiments must be repeated for each variety. In Fig. 52 is given the thickness-voltage chart in use in our laboratories. This shows lines for each of several varieties of intensifying screens and lines for the exposures of films of extremities and other thin parts without screens. All of the thickness-voltage determinations on this chart were made by experimental exposures through paraffin blocks, essentially as outlined in the above experiments. Details of the experiments for voltage-thickness determinations for non-screen exposures have been omitted, but they are carried out essentially as the others.

Experiment 10.

Object.—To prove that the thickness-voltage chart has been correctly made.

If the thickness-voltage chart has been correctly made, it should be possible to select from it the voltage appropriate for any thickness of paraffin from the lowest to the highest that is represented. Although voltages for paraffin thicknesses between those in the experiments have not been determined, experience has taught that the chart should give them correctly. To prove this, expose another film as in the other experiments, using voltages increasing in regular intervals from the lowest on the chart, making the exposures through the corresponding thicknesses of paraffin selected from the chart.

When this film has been completed, an examination of it should show all of the areas to have almost exactly the same density. Because the greater scattering of rays produced by the higher voltages in passing through the thicker masses of paraffin will diminish detail and contrast on those areas, detail and contrast will be better on the areas exposed with the lower voltages.

When the experiments have been completed, if the chart proves to be satisfactory, it is ready for use and may be pasted on a piece of cardboard, covered with a cleaned film, and mounted on the wall by the control cabinet.

OTHER EXPERIMENTS WITH PARAFFIN BLOCKS.

Although the experiments detailed in this chapter are intended for x-ray machines that have been calibrated, and are for the specific purpose of making a thickness-voltage chart, similar experimental

exposures through blocks of paraffin can be made with any transformer type machine with autotransformer control of the primary and secondary voltage, using a hot-cathode tube, and the results incorporated in a chart that may be made the basis for a roentgenographic exposure technique. If exposures be made to determine a thickness of paraffin suitable for a certain voltage, the exposure factors should be kept constant and the thickness of paraffin changed. On the other hand, if the time that will give a suitable exposure is being determined, the paraffin thickness and all the other factors should be kept constant, the time of the exposures being changed.

Among others, experimental exposures may be used under the following conditions:

1. A point-gap calibration of an x-ray machine made at any altitude may be used as an accurate calibration as long as the exposure chart is based on the actual Roentgen-ray output as determined by experimental exposures. In such instances it would be wise to determine the approximate value of the highest voltage so as not to exceed the capacity of the tubes.

2. With machines that are equipped with voltmeters but have not been calibrated, voltmeter readings at regular intervals may be taken as the indicators of secondary voltage and the output for each voltmeter reading determined by experimental exposures. The voltmeter readings may be made the ordinates of the chart instead of the actual voltage values used in Fig. 52. Such voltmeter readings may be either in alternating current volts, in effective or peak kilovolts, or in the arbitrary divisions of a so-called potential indicator.

3. With a machine that has neither a voltmeter nor a spark gap and has not been calibrated, even the control settings may be used as indicators of secondary voltages, experimental exposures being made with control settings at regular intervals to determine the Roentgen-ray output, the control settings being made the ordinates of the exposure chart. If the primary current be variable, with a machine of this kind the best results cannot be expected with any sort of technique.

4. With machines that have large steps in the secondary voltage and which do not have a rheostat, or on which it is not advisable to use the rheostat, a chart like the one in Fig. 53 should be prepared. In experiments for a chart of this kind the voltage and the thickness of paraffin are kept constant, the time of the exposures being varied. The finished films are studied to determine the time that gives the optimum exposure, the exposure times in seconds being the ordinates of the exposure chart.

If the experimental exposures through paraffin blocks be made

with a machine that has not been calibrated in a manner similar to that given in Experiments 1 and 3, as in 2, 3, and 4 above, it must be remembered that any change in milliamperage will cause a change in voltage which may require additional exposures to determine the effect of such changes on the Roentgen-ray output.

All experimental exposures through paraffin blocks should be carefully planned and outlined before they are attempted. A complete record of each experiment should be kept. A 4- by 6-inch card that may be attached to the finished film with a paper clip is suitable for this purpose. This card should show the number of the experiment which should agree with that on the film. It also should show the number of each exposed area and the exact details of the exposure of each area. In addition to the number of the area, these details include the anode-film distance, the milliamperage, the time of the exposure, the number of milliampere-seconds, the voltage applied to the tube, the voltmeter reading, and the thickness of paraffin used. The records of each experiment and the exposed films should be carefully preserved for future reference and study.

In any and all experimental exposures performed for the purpose of determining the Roentgen-ray output of a machine, the standard development of films should be followed (Chapter V).

CHAPTER IX.

ROENTGENOGRAMS.

WHEN a roentgenogram is examined with a suitable viewing light, it is seen to be made up of lighter and darker portions. All gradations often are present extending from complete transparency, transmitting all of the light, through increasing shades of gray and black to an opacity so complete that none of the light is transmitted. These lighter and darker portions are more or less well defined and separated from each other. In places the demarcation is quite abrupt and distinct; in other places the transition is progressive; the different shades may cover a considerable area, or there may be an intricate pattern of lighter and darker areas on the film.

These lighter and darker areas on roentgenograms represent the differences in the density of the structures or parts of the body through which the rays have passed to reach the intensifying screens and the film, the finished roentgenogram being a shadowgraphic pictorial representation of these differences in density. When structures of considerable difference in density like bone and flesh lie side by side, their differentiation is marked; if the differences in density be slight, as between the kidneys and the surrounding tissues, the shadows will show but little variation in shade. If there be no appreciable difference in density of two structures lying side by side, neither will be lighter nor darker than the other, and there will be no differentiation on the film.

Natural differences in density of sufficient degree to permit satisfactory roentgenography are found in many parts of the body. As examples of shadows caused by structures of increased density, those of bones and of the different constituents of the teeth may be mentioned. On soft tissue roentgenograms the shadows of muscle masses, tendons, and even some of the larger vessels may be dense enough to be shown. Air in the lungs, in the nasal accessory sinuses, and in the mastoid cells decreases the density of these structures and causes shadows on films.

When natural differences in density do not exist, it often is possible to create an artificial difference that serves the purpose quite as well. Perhaps the best known of these is the addition of barium sulphate to the stomach and intestinal contents, thus making them opaque to x-rays. Since the stomach fits closely around its contents, much information of diagnostic value can be obtained about its size, shape, etc., and even about the folds in its interior from the examination

of the material it contains. Pyelography, cholecystography, the injection of discharging sinuses, pneumoperitoneum, and iodized oil injections into the bronchi and lungs all include the creation of an artificial difference in density for the purpose of roentgenological study.

In the production of shadows of objects of different sizes and shape, Roentgen-rays act very much like light. The resultant shadows depend on a number of factors. Among these are the size and shape of the object, the aspect it presents to the light, the distance of the object from the light and from the object to the surface on which the shadow falls, the source of the light, whether from a point or a surface, the direction of the rays striking the object, the intensity of the light, etc. By taking objects of different sizes and shapes, holding them in a light from a single electric lamp, and examining the shadows they cast as they are turned with different aspects to the light, much information of value about shadow formation can be obtained.

When the light is close to an object and the object is some distance from the surface on which the shadow falls, the shadow always is larger than the object itself. The amount of enlargement varies with the distance from the surface and the distance of the light from the object. If the object be directly on the surface and the light a considerable distance away, the shadow may closely approach the exact size of the object.

An object in the shape of a sphere, if held in the path of light rays striking a surface perpendicularly, will have a shadow of the same shape, irrespective of the aspect of the sphere that is presented to the light. Moved out of the perpendicular rays, even the shadow of a sphere loses its circular shape and becomes oval. The shadow of an object of any other shape will depend on the aspect that is presented to the light. In the perpendicular rays from a light, a match box, for example, will cast a shadow of three different sizes and shapes, depending on whether the top or bottom, a side, or an end is toward the light; a shadow cast by a cylinder will have a rectangular shape if the side be toward the light or a circular shadow if an end be toward the light. A hollow cylinder on end directly in the perpendicular rays from a light will cause a ring-shaped shadow.

An object will have a shadow of a certain size and shape when in the perpendicular rays from a light; if moved so that the rays strike the object and the surface at an angle, the shadow will have a different shape. This distortion will vary with the obliquity of the rays of light and may be so marked that the shape of the object cannot be inferred from the shape of its shadow.

From this discussion of shadow formation it is obvious that the size and shape of an object can best be determined from its shadow if the object be in proximity to the surface on which the shadow falls, if the intercepted rays be perpendicular to the object, and if the position of the object be such that its size and shape are most correctly reflected in its shadow.

If the light comes from a small source, and if the object be close to the surface on which the shadow falls, the margins of a shadow will be well defined. If the light source be a point, or if the object be near a surface, the margins of the shadow will be clear cut and sharp. If the light comes from a source larger than a point and if the object be removed from the surface, the margins of the shadow will be indistinct and ill-defined.

The shadows of different portions of the body as shown on roentgenograms are formed in much the same way and obey the same laws of shadow formation as do those of solid objects formed by light. In addition the roentgenogram frequently is complicated further by the presence on it of shadows of several portions of the body. All structures through which the rays pass, soft tissues as well as bones and other solid parts—those portions farthest from as well as those nearest the film—contribute to the shadow formation on the film. The best roentgenograms are those that show to best advantage the shadows of the structures they are intended to portray.

Quality in roentgenograms is made up of four different properties or attributes. These properties are known as density, contrast, detail, and distortion. Often they cannot be present in a roentgenogram to the same degree. Sometimes one or more of them is more desirable than the others which makes it necessary to sacrifice the less to bring out the more desirable property. Since these properties are those that contribute quality to roentgenograms, every student of roentgenography should have a thorough understanding of them, should know the basis on which each depends, and should be familiar with the methods and procedures of producing them.

By density is meant the degree of blackening of the films. Density depends on the amount of the silver in the emulsion that has been affected and reduced to a metallic state during development; it is directly proportional to the quantity of rays that reach the emulsion and the fluorescent surfaces of the screens.

Variations in density may exist in a series of films and all of them be of good quality. Optimum density is a matter of personal choice. Some persons like darker films and others those not so dark. As a rule the density of films of parts of the skeleton should be slightly

greater than would be best for films of soft tissues. For example, the shadows of the kidneys will be more distinct on films of slightly less density than would be considered best for films of the adjacent lumbar vertebræ. Perhaps films of average density are best for all purposes.

The density of films may be influenced in several ways. If a film with a greater density be desired, it may be obtained by increasing either the milliamperage, the time, the voltage, or by decreasing the anode-film distance. Of these an increase in the voltage will have the most pronounced effect but also will reduce contrast. If there be no contraindications, it is preferable to secure an increase in the density by increasing the time, or the milliamperage, or both. A decrease in density may be secured by decreasing the time, the milliamperage, or the voltage, or by increasing the distance. Probably the most common cause for too great a density (overexposure) is the use of too high a voltage. Since a decrease in voltage or an increase in distance will not only give a diminished density but also will increase contrast and detail, as a general rule such changes should be made when a decrease in density is desirable.

By contrast is meant the differences in density between the lighter and darker portions of the films. On films of good contrast the shadows of the denser structures show but little blackening, while the shadows of less dense structures appear quite black. The best films are those which show considerable contrast.

Other conditions being the same, the greatest contrast is present on films exposed with the lowest possible voltage. To compensate for the low voltage, the quantity of rays, as represented by the milliamperage and the time, must be large. Under such conditions the low voltage will produce rays of relatively longer wave-lengths and less penetrating ability—rays that are well absorbed by the denser structures of the part resulting in lighter images on the films. The same rays will penetrate structures of less density and cause their shadows to be dark on the finished films. If more penetrating rays be used, the denser structures will not absorb so large a proportion of the rays and less contrast will result.

For the same reasons films taken with intensifying screens will have more contrast than those of the same part taken without screens. This is true even of thin parts like the hands and feet. Rays produced by much lower voltage, and therefore much less penetrating, may be used to cause fluorescence of screens, when without screens much more penetrating rays are required.

Scattered radiation will diminish and when present in any considerable quantity will destroy contrast. In passing through the part, the rays are diverted from their paths at all levels and reach

the screens and films from all directions, spreading over their surfaces like a fog. Loss of contrast from scattered radiation is greatest under those conditions producing the most scattered rays—large parts of the body on large film areas, the use of high voltages, relatively low milliamperages, and short exposure times.

Because of the importance of scattered radiation in lessening contrast, x-ray exposures should never be made without the use of such measures as are available and advisable to limit scattered radiation. The best of these is through the use of a Potter-Bucky diaphragm which will remove 80 per cent or more of the scattered rays. The common diaphragm is not suitable for exposures of less than one second. When short exposures are made, scattered radiation may be reduced by using the lowest voltage with the highest milliamperage, by using a wafer grid, and by the use of cones and diaphragms. Some roentgenologists think that in certain instances, as in exposing films of the mastoid processes and nasal accessory sinuses for example, the Potter-Bucky diaphragm diminishes detail. To preserve detail and limit scattered radiation at the same time, they advocate the use of the smallest possible cone or diaphragm, one just large enough to include the region being examined.

Detail is the sharpness with which the finer subdivisions of the shadows are shown on films, their margins, edges, contour lines, variations in density, etc. When detail is good, the cancelli in spongy bone, bone edges, fine markings within the lung shadows, outlines of the kidneys or barium-filled portions of the alimentary canal, the margins of muscle masses, etc., are shown without haziness and with good definition. Good detail is the most important quality of x-ray films, and while it often is most apparent on films of good contrast, contrast and other properties must frequently be sacrificed to secure it.

There are a number of factors that influence the detail on x-ray films. Among these may be mentioned the size of the focal spot of the tube, immobilization of the part of the body or structures of the body being examined, the contact between film surfaces and intensifying screens, the distance of the structures from the film surface, and the anode-film distance.

Perhaps of most importance is the size of the focal spot of the tube. With a small focal spot the rays originate from a surface that approaches a point in size; rays from a point will produce the sharpest images. A larger area in the focal spot acts like a number of points, each tending to produce its own image, thus causing blurring and loss of detail on the films. Whenever immobilization permits a long exposure, tubes with small focal spots should be

used. Since the projected focal spots of the line or band focus tubes are much smaller than those of the round focus tubes, the former give much better detail than the latter.

Tube stands must be rigid and x-ray tubes absolutely stationary during roentgenographic exposures. If there be any vibration of the tube, like that caused by swaying or vibration of the tube stand, the effect is the same as having a focal spot the size of the full range of motion of the tube. All the advantages of a small focal spot may be destroyed by as much as 1 or 2 millimeters sway in each direction of the tube during an exposure.

Other factors being equal, better detail with the least distortion will show on films made with the longest anode-film distance; the rays from the focal spot of the tube will be more nearly parallel and will diverge less between the body structure and the surface of the film. Even a tube with a large focal spot will give good detail if the distance be long enough. Martin and Holmes found that the same definition was obtained on films with the 10-milliampere radiator type Coolidge tube and the fine, medium, and broad focus universal Coolidge tubes at anode-film distances of 26 inches, 3 feet, 4 feet, and 5 feet respectively.

Detail on films of a part of the body is better if that part be as close as possible to the surface of the film. The rays do not have an opportunity to spread out after passing through the part before reaching the film surfaces. For this reason, in exposing films, that particular portion of the part of the body that is being examined always is placed as close as possible to the film. Procedures for doing this are adequately covered in the sections on regional roentgenography.

Movement while an exposure is being made will diminish or destroy detail. Under movements must be included movements of the body as a whole, movements of a part of the body, respiratory motion when films of the thoracic and abdominal viscera are exposed, and movements of the viscera themselves. Rapidity of exposure must be relied upon to secure good detail on films of the stomach with an active peristalsis and to overcome haziness in the shadows of lung structures from movements transmitted by cardiac contractions. Rapid exposures also lessen the likelihood of breathing during exposures of the thorax and abdomen.

Rapid exposures require a high voltage, a high milliamperage or both. The only tube with which these are permissible, at the same time retaining the advantages of a small focal spot, is a rotating-anode tube. For high energy exposures with a stationary anode tube a large focal spot is necessary. To secure good detail with stationary anode tubes, two widely different procedures must be

used, a long exposure with a small focal spot for parts that can be immobilized, and a short exposure with a large focal spot to prevent loss of detail by blurring from involuntary and uncontrollable motion. To meet these two conditions and to obviate the necessity of changing, tubes with double focal spots were developed. Short high-energy exposures—with the finest focal spot—conditions giving finest detail—are possible only with rotating-anode tubes.

A common cause of lack of detail on roentgenograms is poor contact between the emulsion surfaces of films and fluorescent surfaces of intensifying screens. If contact be imperfect, light originating from a spot, a line, or area of the screen will spread over a larger area of film, causing a blurring of shadows on that portion. Usually lack of detail from this cause is not uniform over the whole film surface, but in one or more patches of irregular sizes and shapes (see page 85).

Contrast and detail are different qualities of roentgenograms, yet they are closely related. It is possible to have films with good detail that show little contrast. It also is possible to have films with excellent contrast and poor detail. However, good contrast is necessary to bring out and make good detail more evident. This particularly is true with reference to loss of contrast by scattered radiation, for scattered radiation also will destroy good detail.

On films of thin parts, as the extremities, for the exposure of which screens are not necessary to obtain good contrast, the best detail will be secured if the films be exposed without screens. In many laboratories films in cardboard exposure holders are used for this purpose.

Distortion is the variation from the true size and shape of images of parts of the body when they are projected on to and registered on a film. Since the rays originate from a very small area and spread out in a hemispherical shape which is reduced to a cone by diaphragming, the image of a part of the body on a film always is larger than the part itself. This increase in size is variable. It depends on the distance of the part from the film, on the size of the part, and on the distance of the tube anode from the film. There will be considerable increase in the size of the shadow of a small object some distance from the film, of a large object either removed from or close to the film, while the distortion of a small object near the film is least of all.

Since a long anode-film distance reduces distortion in size to a minimum, the longest practicable distance should always be used. Even images of such a large object as the heart may be obtained with little distortion if the distance be long enough. This is the reason

for exposing films of the heart at a distance of 6 or 7 feet. Usually, however, the exact size of the images of structures on films is of such little consequence that distortion in size does not detract from the value of the films.

Distortion in shape perhaps is more pronounced than distortion in size. This especially is true if a large film of a large part of the body be made. In the center of the cone the Roentgen-rays will pass directly through the part, producing relatively undistorted images of the structures in their path. From the center of the cone toward the periphery the rays increase in obliquity, because of which the images of structures will be increasingly distorted. The margins or edges of structures near the center of the film will be distorted less than those removed from the center.

Distortion cannot be eliminated, but by careful posing of the patient and placing of the film and tube, it may be kept at a minimum.

FILM FOG AND FILM DEFECTS.

The silver-laden emulsion on *x*-ray films is a sensitive layer, and the procedures collectively making up the processing of exposed *x*-ray films are delicate chemical reactions. Unless the films are stored and handled before and during development in an exact and precise manner, there are divers accidents more or less critical that may happen to them. They may be fogged during storage or by improper development and they may be marked or spotted in various ways that detract from the appearance of the finished roentgenograms.

Fog is the development of silver particles in the emulsion other than those affected by the Roentgen-rays during the exposure. When uniform, it appears on the developed films as a grayish or darker discoloration; when not uniform the discoloration is patchy or spotted. Perhaps the most common cause of fog is exposure to Roentgen-rays. *X*-ray films stored in proximity to an active *x*-ray tube should be completely surrounded by lead in a lead-lined box or film safe. A box of unused films, a loaded cassette, or an open film storage box in or near an *x*-ray room may be accidentally fogged by as little Roentgen-rays as would be scattered during a single exposure. The Eastman Kodak Company has placed a narrow strip of lead foil in the boxes in which its films are sold. On these films the presence of a narrow, lighter streak across a developed film is evidence that that film has been fogged by Roentgen-rays before it was removed from the box.

Films may be fogged during development. When the temperature of the developer is too high, fog often will result. Every inspec-

tion of a developing film with a dark-room light will cause some fog, both from the illumination and from oxidation of the developer on the film. Repeated inspection of developing films may cause serious fog. Overdevelopment will cause fog. The examination of a film in an illuminator or the exposure of films to white light in a fixing bath before fixation is complete will cause an opalescent fog.

Most *x*-ray workers are familiar with static markings on *x*-ray films. Tree-like, branching, black static markings are most familiar; less so are hazy and spotted woolly markings also due to static electrical discharges. The tree-like marks are from static caused by friction; the others are caused primarily by pressure. The static charges may collect on the films in the cassettes or they may accumulate on the person of the operator and be discharged to the film during contact. A humid atmosphere, the reduction of friction to a minimum, the avoidance of undue pressure on the films, the slow opening of cassettes to allow static charges time to dissipate, and the touching of a grounded object before handling a film are recommended for the abolition of static markings from *x*-ray films.

Other film defects which may appear occasionally are finger prints from damp, dirty fingers; crescentic dark or light markings from buckling the film during handling; stains of various kinds, the most common of which is a yellowish to brownish discoloration from insufficient rinsing between developer and fixing bath, and many kinds of defects from imperfections in screen surfaces.

The production of good roentgenograms is an art. A knowledge of the different natural and artificial densities of the body, an understanding of the laws governing shadow formation, an appreciation of the properties that govern film quality, the selection of groups of exposure factors to balance density, contrast, and detail, and the exact handling of films to minimize defects are all essential for the best results.

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CHAPTER X.

COMBINATIONS OF EXPOSURE FACTORS.

IN the introduction of Chapter VI one of the requirements for skill in roentgenographic technique is listed as the ability to select correct combinations of factors for exposing films of any part of the body. This part of roentgenographic technique will be discussed in detail in this chapter.

In this discussion the combinations of factors have been grouped under five headings. These are the extremities, the abdominal viscera, films exposed with a Potter-Bucky diaphragm or a wafer grid, the thorax through the lungs, and the parts of the head and skull. Under each of these headings a number of combinations of factors are given. Ordinarily one or two of these are all that are necessary. The others are included to give wide personal choice in the selection of the most desirable and to meet unusual conditions which may arise.

In the selection of the exposure factors in the various combinations, the principles given in Chapter VII for a basic roentgenographic technique have been followed. In all of them as many as possible of the factors have been kept constant, the voltage through the tube being the one most often varied. In the selection of the proper voltage a thickness-voltage chart (Fig. 52) has been used throughout. Provision has been made for different intensifying screens by basing the voltage selection on the kind of screens being used, without changing the other factors. Use has also been made of the charts and tables given in Chapter VI including the calibration charts and those illustrating the laws which govern roentgenographic exposures.

Those given in this chapter do not exhaust by any means the possible combinations that may be used with good results. With a basic technique as the foundation, combinations like the ones given, or any others that appear more desirable, may be obtained from it by making one or more of the following changes:

1. Making changes in the anode-film distance to permit of changes in the exposure time.

These are based on the law that the intensity of a roentgenographic exposure varies inversely as the square of the anode-film distance (Experiment 5). As examples, changing from a 35-inch distance to one of 25 inches reduces the time one-half; from 35 to 48 inches requires that the time be doubled, etc. (see Figs. 48 and 49; also page 123).

2. Increasing the milliamperage to reduce the exposure time.

These are based on the law that the intensity of an exposure varies directly as the milliamperage (Experiment 4). Possible changes in milliamperage, especially with the higher capacity tubes, are numerous. The milliamperage may be doubled, reducing the time one-half; it may be increased from 20 to 60 or 80 with corresponding decreases in time; or it may be increased under certain conditions to as much as 100, thus permitting of very short exposures. With rotating-anode tubes short exposures using 100 or more milliamperes can be the rule instead of the exception.

3. Increasing the voltage in order to shorten the exposure. A study of Fig. 51 will show that there can be no set rule that this or that amount of increased voltage will always have the same effect. However, with a suitable thickness-voltage chart from which to obtain the proper original voltage, the addition of voltage as given in Fig. 51 can be used to shorten exposures.

Other essentials in a roentgenographic exposure technique, such as the differences in density of the tissues, the absorption of rays by the grid of a Potter-Bucky diaphragm, etc., will be discussed in their proper places.

In the use of this technique it must be emphasized again that there may be marked differences in the characteristics and possibly in the thickness-voltage relations of different equipments, and that the best results can only be expected when exposures are based on charts and tables and a thickness-voltage chart prepared with the equipment with which they are to be used. In addition to the thickness-voltage chart, when required, the most important of these, and ones that are absolutely essential for satisfactory work, are the calibration charts like those from Experiment 3, showing the manner of obtaining the various secondary voltages with different milliamperages.

EXPOSURE COMBINATIONS FOR FILMS OF THE EXTREMITIES.

Films of the extremities may be exposed with or without intensifying screens. Whether or not screens are used depends on several factors. Chief of these is the personal choice of the technician or the roentgenologist, many preferring the better detail on films without screens to the greater contrast on films exposed with screens. Perhaps of equal importance are the lower voltages that can be obtained from the equipment. In order to use screens to best advantage, the lowest voltage should not be much more than 30 peak kilovolts, and there must be small voltage intervals, preferably as small as 1 or 2 peak kilovolts. The importance of this will be seen in a

critical examination of Fig. 52, the thickness-voltage chart. This shows that there is relatively little difference in the voltages required for the different types of intensifying screens in the lower voltage ranges and that a considerable extent of thickness is covered by the lower voltages.

Whether or not screens are used, the factors given in the basic technique can be used for films of any part of the extremities. This means that using 20 milliamperes for five seconds at an anode-film distance of 35 inches, with the voltage based on the thickness of the part and the kind of photographic material being used, roentgenograms of good quality of any part of the extremities will be the result. If the lowest voltage be too high for screen exposures of the thinnest parts, the time may be reduced to four, three, two, or even one second. When this is necessary for films with screens, it is preferable to use films without screens, with voltage from the proper line on the thickness-voltage chart and the other factors unchanged.

The above technique is based on the assumption that all parts of the extremities of all persons are of exactly the same density, and that variations are only required for differences in thickness. Some differences in density do exist, but they are so slight that a special technique usually is not required. If one wishes to allow for differences in density in exposing films of parts of elderly people, of parts that have been immobilized for some time, and those of smaller children, a voltage of 2 or 3 peak kilovolts (¼-inch spark gap) less than that given in the thickness-voltage chart will fulfill all requirements.

Under unusual conditions, as when examining a struggling or crying child, or when for any reason immobilization of the part cannot be secured, by using information obtained from the various tables and charts the time can be so shortened that an interval of quiet sufficient to make an exposure can be caught. The distance may be reduced to 25 inches, thus shortening the time one-half, or to two and a half seconds (Fig. 49). If the tube permits, at this distance the milliamperage may be increased to 50 reducing the time to one second, or to 100 reducing the time to one-half second. To obtain the same voltage with higher milliamperage, the primary voltage must be increased. If a further reduction in time be necessary, enough additional voltage can be added to the secondary current to decrease the time. The voltage to be added varies with the thickness, the original voltage, and the kind of intensifying screens being used (Fig. 51). From the thickness-voltage chart and the voltage-increase chart, a table of exposures may be made and kept handy for reference. Using Eastman High-Definition screens with other factors from the basic technique and with voltage from the

thickness-voltage chart, the beginning of such a chart will be as follows:

Thickness in centimeters	Original voltage	Time of exposure after voltage has been added (sec.)		
		+10 P.K.V.	+15 P.K.V.	+20 P.K.V.
5	30	.6	.3	.15
6	31	.65	.35	.2
7	33	.75	.4	.25
8	35	.85	.5	.3
9	36	.9	.55	.35
10	37	1.0	.6	.4
etc.	etc.	etc.	etc.	etc.

If one wishes the greater definition on films exposed at higher voltages rather than the greater contrast on films exposed at lower voltages, as suggested by Fuchs, a chart like the above will aid in the selection of the proper factors.

If the above changes have been made correctly, the resulting films will have the same density as if the basic technique had been followed. The quality will not be quite as good. There will be more distortion and slightly less detail at 25 inches than at the longer distance. There will be less contrast on films made with the higher voltages. Yet for all ordinary purposes, the films will be of good diagnostic quality.

This technique for extremities may be summarized as follows:

Distance 35 inches
Milliamperes 20
Time five seconds
Voltage appropriate for the thickness from the thickness-voltage chart.

Modifications:

1. Distance 25 inches
   Time two and a half seconds
   Other factors unchanged.
2. Distance 25 inches
   Milliamperes 50
   Time one second
   Voltage unchanged.
3. Distance 25 inches
   Milliamperes 100
   Time one-half second
   Voltage unchanged.
4. Distance 25 or 35 inches
   Milliamperes 20 or more
   Time depending on voltage increase from the voltage-increase chart (Fig. 51).

EXPOSURE COMBINATIONS FOR FILMS OF THE ABDOMINAL VISCERA.

In the examination of the abdominal viscera, large film areas often are required and the abdomen may be of considerable thickness. Under such circumstances the deleterious effects of scattered radiation on the films are maximal. To overcome the loss of detail and contrast from scattered radiation, it is necessary to use a Potter-Bucky diaphragm or a wafer grid. In fully equipped laboratories most such exposures are made with one or the other of these aids. Because some equipments may not include a diaphragm or a grid, a general discussion of exposures of the abdominal viscera is included in this section and combinations of factors are given for them. Combinations for exposures with a diaphragm or a grid will be found in following sections.

Because of the likelihood of blurring from motion on films of the abdominal viscera, long exposures through the abdomen are impracticable. Abdominal movements are of two kinds: respiratory motion transmitted from the thorax and motion of the viscera themselves. During the exposure of films respiration must be suspended. The absolute cessation of respiration for any length of time probably is rarely accomplished, while it often is difficult to secure even a relative stoppage of respiratory motion. The peristaltic activity of the viscera, of course, is beyond control.

These two types of motion increase the difficulty of roentgenography of the abdominal viscera. An exposure time of five seconds for films of the kidneys, appendix, and colon, of two and a half or three seconds for the gall bladder, and of one second for the stomach and small intestine probably are the upper limits for these structures. If the time can be reduced half in each instance, there will be less likelihood of having the films spoiled by movements.

The density of different parts of the abdomen of the same thickness is not exactly the same, that of the upper portion through the liver, gall-bladder region, and kidneys usually being greater than that of the middle and lower portions. Frequently the thickness of the abdomen is not uniform. In a fat person in the prone position the greater thickness may be through the upper portion. In a thinner person, particularly a slender female with a thick pelvis, the lower part of the abdomen may be considerably thicker than the upper. In exposing films of the whole abdomen or a major portion of it, it may be impossible fully to compensate for these differences. It is possible partially to equalize the exposures by having the cathode end of the *x*-ray tube (particularly a line or band focus tube) directed toward the thicker or denser portion (see p. 199).

As a basis for roentgenographic exposures of the abdominal viscera, simple modifications of the basic technique will suffice. To minimize distortion, when possible it is well to use as great an anode-film distance as possible. If an equipment with a capacity of 100 milliamperes be available, 100 milliamperes for one second or 50 milliamperes for two seconds may be used. These retain the quantity of Roentgen-rays given in the basic technique, permitting the use of the voltage proper for the thickness and obtained from the thickness-voltage chart. By reducing the distance from 35 to 25 inches, the time of these exposures may be reduced one-half. At an anode-film distance of 25 inches 100 milliamperes for half a second or 50 milliamperes for one second will be suitable, with the voltage from the thickness-voltage chart.

If the capacity of the equipment be less than 100 milliamperes, then the distance must be decreased to 25 inches, the full milliamperage used, and voltage be added to the original voltage to reduce the exposure time within the limits required by the examination. The amount of added voltage cannot be accurately stated, but it may be determined from the thickness-voltage and voltage-increase charts. It may also be obtained from a table like that suggested on page 168. It is almost impossible to make satisfactory films of parts of the gastrointestinal tract with a unit type or self-rectifying apparatus with a capacity less than 30 milliamperes.

These modifications of the basic technique may be summarized as follows:

1. Distance 35 inches
   Milliamperes 50
   Time two seconds
   Voltage appropriate for the thickness from the thickness-voltage chart.
2. Distance 35 inches
   Milliamperes 100
   Time one second
   Voltage appropriate for the thickness from the thickness-voltage chart.
3. Distance 25 inches
   Milliamperes 50
   Time one second
   Voltage appropriate for the thickness from the thickness-voltage chart.
4. Distance 25 inches
   Milliamperes 100
   Time one-half second
   Voltage appropriate for the thickness from the thickness-voltage chart.

5. Other modifications to decrease time by the addition of voltage the exact figures for which cannot be given but which can be determined from the basic technique and the voltage-increase chart.

EXPOSURE COMBINATIONS FOR FILMS WITH A POTTER-BUCKY DIAPHRAGM.

A Potter-Bucky diaphragm is the most practical device for the absorption of scattered radiation in roentgenography. Films exposed with the aid of one show much better contrast than those exposed without. While it may be possible to produce small film areas the diagnostic quality of which is as good as those exposed with a diaphragm, this is impossible for larger parts or regions of the body and larger films. Except for some films of the extremities and the usual exposures of the lungs, a diaphragm may now be used for any part of the body. In this section combinations of factors will be given for exposures of those portions of the body that are of average density. These include the extremities, shoulders, hips, pelvis, abdomen and abdominal viscera, cervical and lumbar portions of the spine, and the thoracic portion of the spine in the anteroposterior direction. The use of the diaphragm for other parts of the body will be discussed under those headings.

The absorption of Roentgen-rays by the lead strips of the grid makes necessary a special exposure technique for use with a Potter-Bucky diaphragm. The Potter-Bucky diaphragm exposure factor is the factor by which exposures with screens alone must be multiplied when using a diaphragm to obtain the same radiographic density. Smith says that, with the tube properly centered, manufacturers have designed grids so that the exposure factor is almost exactly 3. From experiments and practical experience, using five different diaphragms made by four manufacturers, this has been found correct. This does not include experiences with grids having 8 to 1 ratios nor those with high-speed grids of other ratios. Elsewhere this factor has been given as 3.5 and 4, but for the usual diaphragm 3 is thought to be more nearly correct. If there be any doubt about the diaphragm exposure factor in a given instance, probably it should be independently determined.

The older curved-top and some of the older flat-topped Potter-Bucky diaphragms had radii of 25 inches, meaning that the planes of all the grid strips converged at a distance of 25 inches from the grid. In use, these were designed to function with the anode of the tube 25 inches from the grid and focused over its center. This short anode-grid distance, with the thicker grids then in use, caused con-

siderable distortion by separating the part being examined from the films. Newer grids, mostly flat-top models, have radii of 30 or 36 inches (some even 48 inches), the grids are much thinner, and distortion from separation of patient and film is much less.

Although the radius of each diaphragm grid is the distance at which the anode of the tube should be centered for most effective operation of the grid, with the possible exception of grids with an 8 to 1 ratio, it is possible to use greater distances. Since distortion with distances of 30 to 35 inches is less than with 25 inches, this is often desirable with the older diaphragms. When large films are exposed at these longer distances, there may be more absorption of the rays along the sides of the diaphragm and the films; usually the lateral portions of the body are thinner than the central portions and the greater absorption prevents overexposure of these thinner parts. An anode-grid distance of 36 inches was recommended by Lawrence to prevent overblackening of the shadows of the iliac crests, greater trochanters of the femora, and the flanks on large films of the abdomen and pelvis. For the same reason the greater distance may be used in the exposures of other parts of the body.

In devising sets of factors for the exposure of films with the aid of a Potter-Bucky diaphragm, the intensity must be multiplied by the exposure factor to compensate for absorption of the grid. In most instances this will be 3. With the basic technique as a foundation this increased intensity may be obtained by increasing the quantity of Roentgen-rays as represented by the milliampere-seconds. Instead of the 100 milliampere-seconds given in the basic technique, this may be 300 milliampere-seconds at an anode-film distance of 35 inches, 225 at a 30-inch distance, and 200 at a 25-inch distance. In each instance the voltage is appropriate for the thickness and the kind of intensifying screens being used as obtained from the thickness-voltage chart (Fig. 52). With parts that can be immobilized for long exposures, like the vertebral column, even a small focus stationary anode tube can be used for such exposures, 30 milliamperes for ten seconds, 25 milliamperes for nine seconds; 20 milliamperes for ten seconds, etc. With the larger focal areas of stationary anode tubes, other combinations of milliamperage and time may be used. If a tube be capable of delivering 100 milliamperes, this value for three, two and a fourth, and two seconds will give the same intensity. With rotating-anode tubes no difficulty should be experienced in obtaining the required intensity.

In using a Potter-Bucky diaphragm, it is also possible to compensate for the absorption of the grid by increasing the voltage of the basic technique. As in other increases this will be less with low than with high original voltages. From experimental exposures

and practical experiences this has been found to be about 5 for an original value of 40 peak kilovolts, 7 to 8 for 50, 10 to 12 for 60, and 15 for 70 peak kilovolts. Since most diaphragm exposures have an original value in the neighborhood of 60 peak kilovolts, 8 or 9 to 12 or 13 added kilovolts will most often be required. The average addition will be about 10.

When absorption of the grid of a Potter-Bucky diaphragm has been corrected by adding voltage, then the factors in the basic technique may again be used. One may take 100 milliampere-seconds at an anode-film distance of 35 inches and add voltage enough to compensate for the absorption of the grid. One hundred milliamperes for one second will give a reasonably short exposure. This exposure may further be shortened by the addition of more voltage. In the range of voltages and thicknesses used in exposures with a Potter-Bucky diaphragm this will most often be in the neighborhood of 10 kilovolts. On the average, diaphragm exposures can be made of the stomach, intestine, gall bladder, etc., by taking the voltage from the thickness-voltage chart and adding 20 peak kilovolts, with 100 milliamperes for half a second at a 35-inch anode-film distance. For the thinner parts this voltage addition may be too much, and for thicker parts it may be too little. If this be true slight changes in the added voltage will correct the exposures.

In exposing stereoscopic films with a Potter-Bucky diaphragm with the tube shift across the grid strips, there is more absorption of the rays by the lead strips of the grid than there is if the tube be over the center of the grid, or if the stereoscopic shift be parallel with the strips. This requires that the exposures be increased 25 per cent, either by increasing the milliampere-seconds or the voltage.

Thicknesses greater than those included in the thickness-voltage chart are encountered in lateral exposures of the abdomen, the lumbar spine, and the lumbosacral region. In selecting factors for such exposures, using a Potter-Bucky diaphragm, a different type of technique must be used. The basis of this may be a relatively low milliamperage, a relatively long anode-film distance to reduce distortion, a high voltage, but one that can be used with tubes having a small focal spot, and a variation in the time of the exposure, depending on the thickness of the part. A technique such as this is graphically shown on the chart in Fig. 57. This is based on 20 milliamperes, a 35-inch anode-grid distance, and 85 peak kilovolts, using high speed intensifying screens. The ordinates of the chart are exposure time in seconds; the abscissæ are thicknesses in centimeters. From this chart the time required for the exposures is obtained. This chart will be found suitable for machines with which

the thickness-voltage chart can be used and is subject to the same limitations.

To prevent confusion, the combinations of factors for use with a Potter-Bucky diaphragm have intentionally been limited. With high energy apparatus and high capacity tubes there is no limit to the number and variety of combinations that can be derived by modifications of the basic technique.

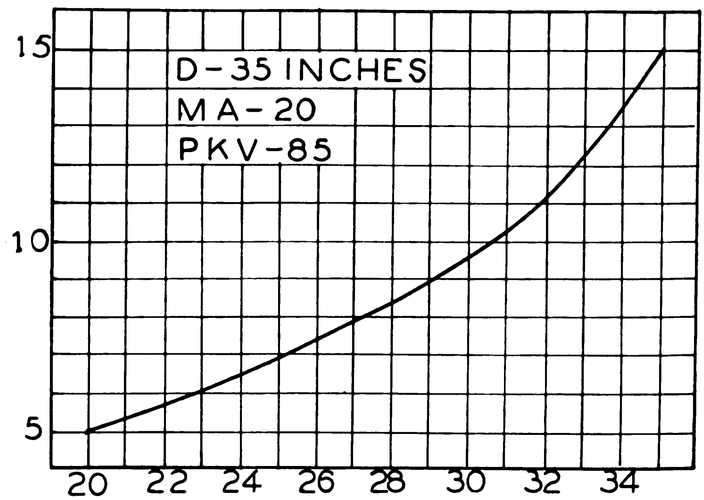

Fig. 57.—An exposure chart for lateral films of the abdomen and lumbar spine with a Potter-Bucky diaphragm. The ordinates are exposure time in seconds; the abscissæ are thickness in centimeters. The constant factors are given on the chart. High speed screens were used.

The most useful combination of factors for exposures with a Potter-Bucky diaphragm may be summarized as follows:

1. For exposures of parts that can be immobilized using a small focal spot in a stationary anode tube.
   Distance 35 inches
   Milliamperes 30
   Time ten seconds
   Voltage from the thickness-voltage chart.

2. Using a large focus stationary anode tube or a rotating anode tube
   Distance 35 inches
   Milliamperes 100
   Time three seconds
   Voltage from the thickness-voltage chart.

3. For shorter exposures
   Distance 35 inches
   Milliamperes 100
   Time one second
   Voltage from the thickness-voltage chart plus enough to compensate for the absorption of the grid; average 10 kilovolts, or
   Distance 35 inches
   Milliamperes 100
   Time one-half second
   Voltage from the thickness-voltage chart plus enough to compensate for the absorption of the grid and to shorten the exposure one-half, average 20 peak kilovolts.

For stereoscopic films with the tube shift across the grid strips, the intensity must be increased 25 per cent by the addition of milliamperes, time, or voltage.

For films of the abdomen, the lumbar and lumbosacral regions in the lateral direction:

Distance 35 inches
Milliamperes 20
Voltage 85 peak kilovolts
With high speed intensifying screens, time according to the thickness from chart in Fig. 57.

EXPOSURE WITH WAFER GRIDS

A Lysholm grid is a satisfactory device for improving contrast and detail on roentgenograms through the absorption of scattered radiation. It does not seem to be quite as efficient as a Potter-Bucky diaphragm. However, because of portability, the grid can be used for exposures impossible with a diaphragm. The thinness of the grid does not increase distortion to an appreciable degree, and not so much increase in exposure is required as with a diaphragm.

Special combinations of factors are unnecessary for exposures of films using a Lysholm grid. Simple modifications of combinations of factors for films without the grid give good results. The milliamperage, the time, or the voltage may be increased enough to compensate for absorption by the grid. An increase in the milliamperage, the time, or the milliampere-seconds of 30 to 40 per cent is required. This increase seems to be uniform and irrespective of the thickness of the part, the voltage, or the milliampere-seconds of the original exposure.

The addition of voltage to compensate for the absorption by the grid seems to be somewhat variable. With thin parts and low

original voltages the addition of about 5 peak kilovolts will suffice. If the parts be moderately thick and a medium voltage be used, the addition must be 7 or 8 peak kilovolts. For thick parts and high original voltages the addition must be 10 peak kilovolts.

These modifications of any of the combinations of factors given for films of the extremities, for films of the abdominal viscera, for films of the thorax through the lungs, and for those of the head and skull will give good results with a Lysholm grid.

The Liebel-Flarsheim stationary filter grid has a 5 to 1 ratio. Its efficiency in the removal of scattered radiation is about 88 per cent. The factors for use with this grid are the same as those given for a Potter-Bucky diaphragm.

EXPOSURE COMBINATIONS FOR FILMS OF THE THORAX.

The thorax through the lungs is less dense to Roen'gen-rays than any other part of the body of the same thickness. The soft tissues and bone of the thoracic wall are like similar structures elsewhere, but air in the lungs reduces the average density to a marked degree. Exact figures of the proportion of chest wall to lung in the anteroposterior diameter of the thorax could not be found, but measurements made from a series of anatomical cross sections indicate that approximately three-fourths of the thickness in adults is occupied by the lungs.

In addition to the lesser average density, movements must be considered when a roentgenographic technique for the lungs is devised. These are of two kinds: those produced by respiration, and those transmitted to the lungs by cardiac contractions. One who has observed the chest with a fluoroscope can appreciate the extent of these transmitted movements, especially in and around the hilus of the left lung.

In roentgenography of the lungs the diminished density makes it possible to use either less penetrating rays or a smaller quantity of rays, a smaller quantity permitting of a much shorter exposure. To diminish the effects of movements on films of the lungs a rapid exposure is necessary. Other factors being equal, the shortest exposure will give the greatest detail on the films. To minimize distortion, the longest practicable anode-film distance should be used.

Bridges reported on an elaborate and well conducted series of experiments in the exposure of chest roentgenograms. His conclusions were that contrast was best on films exposed with 1000 milliamperes, thus permitting the use of a lower voltage and a more absorbable quality of rays. The best time for exposures was given as one-twentieth and one-thirtieth of a second, with the best quality

on films taken at a distance of from 7 to 8 feet. Four or five different density varieties were found that were satisfactory and difficult to differentiate in quality.

In an excellent series of articles Wilsey considered the physical factors underlying chest roentgenography. He concluded that in reducing distortion and increasing film detail there was no advantage in an anode-film distance greater than 4 feet provided the size of the focal spot of the tube was such that a chest roentgenogram could be taken at this distance by using the tube at near its rated capacity. Under such circumstances he concluded that the best chest roentgenograms would be obtained with present average equipments by an exposure time of one-tenth or one-twentieth of a second and 100 milliamperes with a suitable voltage. Slightly more sharpness of detail would be obtained by using one-twentieth second exposures.

Very rapid exposures at a long distance require accurate timing devices and powerful apparatus. These usually are found only in special laboratories. A moderately short exposure at an average distance, following the findings of Wilsey, can be made with most equipments and, unless special apparatus is available, should be the technique used.

As a basis for roentgenography of the chest through the lungs, it has been found that one-seventh the quantity of Roentgen-rays given for similar thicknesses in other parts of the body in the basic technique will give films of proper density of the thorax of adults. Whereas 100 milliampere-seconds are required for a part of average density, with the voltage from the thickness-voltage chart, approximately one-seventh this quantity or 15 milliampere-seconds will be suitable for a film of the chest of the same thickness, using the same voltage. This fraction should be remembered, for it has been found useful in calculating chest exposures with bedside units and under other unusual circumstances.

If the antero-posterior diameter of the thorax be measured with a pelvimeter or other measuring device at the level of the fifth thoracic vertebra and the voltage selected for this thickness from the thickness-voltage chart, an exposure of 30 milliamperes for one-half second at a 35-inch distance will be correct. The measurement should be made during quiet respiration. Films should be exposed at full inspiration. While the thickness will be greater than when the measurement was made, the increase in thickness is due to inspired air which does not add to the thoracic density. If the milliamperes be increased to 60 and the primary voltage adjusted so that the correct secondary voltage through the tube will be maintained, the time may be reduced to one-fourth second.

This technique can be modified easily for a shorter exposure at a

greater distance. One hundred milliamperes for one-tenth second gives 10 milliampere-seconds; increasing the distance from 35 to 48 inches requires nearly a doubling of the intensity. To compensate for the smaller quantity of rays and the increase in distance, voltage must be added to that appropriate for the thickness as taken from the thickness-voltage chart. Experience has shown that from 7 to 10 peak kilovolts is the required addition; 7 or 8 peak kilovolts for persons with thinner chest walls and 9 or 10 for thick, heavily muscled thoraces.

Should one care to increase the distance to 60 or 72 inches, the addition of 15 kilovolts for the former and of 20 kilovolts for the latter will be found approximately correct. Or should shorter exposures be preferable, the time may be decreased to one-twentieth second, the distance be 48 inches, and the voltage selected from the thickness-voltage chart for the thickness and 20 peak kilovolts added.

In the above discussion of groups of exposure factors suitable for films of the thorax through the lungs, it has been assumed that all thoraces are of the same density. This is not exactly the case. It is probable that most of the roentgenographic density is contributed by the thoracic walls, little by the air-filled lungs. It is probable therefore that thoraces with thicker walls would require a greater increase in the tube voltage than would be expected from the increased thickness. Weyl and Warren give a tube voltage for an average chest: subtract 1 peak kilovolt if the chest is thin with little fat and prominent ribs, add 1 peak kilovolt if there is more muscular tissue than normal, and add 3 peak kilovolts if the chest is extremely fat and muscular.

For films of the lungs in either the right or left oblique directions, and for transverse views of the thorax, special sets of exposure factors are required. For the oblique views, the distance, milliamperage, and voltage for the antero-posterior views may be used, the time being increased to twice that for such views. For films in the transverse direction the other factors may be selected as for the antero-posterior exposure and the time multiplied by 4.

Films of the thorax through the lungs are occasionally exposed with the ordinary Potter-Bucky diaphragm. This is done with patients who have had plastic operations on the thoracic wall, and it is sometimes desirable when there are extensive pathological changes of considerable density within the lungs or pleura or when the chest is examined for injuries. For such exposures the factors should be selected for a similar view without the diaphragm and the time multiplied by 3. Because of distortion a distance less than 35 inches with the diaphragm is not advisable, and because of grid

marks the exposure should not be too short. For Potter-Bucky exposures of the thorax the voltage may be selected from the thickness-voltage chart and the quantity be one-seventh of that of the basic technique or 30 milliamperes for one-half second. Multiplying by 3 for absorption by the Bucky grid would give an exposure time of one and a half seconds.

In the exposure of films of the lungs the sets of factors given are based on the density of normal lung tissues or of that containing relatively little pathological material. In case of extensive involvement and if the character of the involvement be desired, either the milliamperage, time, or voltage must be increased. This increase depends on the amount of involvement and cannot accurately be stated. In such instances the normal lung tissue will be overexposed.

THE THORACES OF CHILDREN.

The thoraces of adults of different thicknesses are of approximately the same roentgenographic density. If a given thickness of the thorax of a child, however, be compared to a similar thickness of the thorax of an adult, the average density to Roentgen-rays of that of the child is considerably greater than that of the adult. This is most marked in infants and gradually decreases as age advances. Scammon found that at birth lung weight and lung volume are approximately equal, at six months the lung volume is approximately 50 per cent greater than lung weight, and by one year it is almost twice as great. This indicates that as a child grows older the proportion of air to solid tissue in the lungs undergoes a marked increase. This change probably continues for some time after the first year. It explains the relatively greater opacity to Roentgen-rays of the thoraces of infants and younger children.

This greater opacity makes necessary a special exposure technique for films of the thorax of infants and children, and its decrease as age advances makes impossible the establishment of a rule, based on thickness, for the exposure of such films. Experience leads to the belief that the increase in the thickness of the thorax as age advances is offset by the increase in the relative amount of air in the lungs. In a young child, when respiration cannot be suspended, the time of the exposure should not be longer than one-tenth second. At a 35-inch distance there is little need or varying the exposure factors for infants and younger children. A voltage appropriate for 16 centimeters from the thickness-voltage chart with 10 milliampere-seconds, irrespective of the age or size up to twelve or fourteen years of age, and an antero-posterior thoracic diameter of approximately 16 centimeters, will give films of good

diagnostic quality. For lateral films add 10 peak kilovolts to the voltage. Above these limits the technique as for adults should be used.

The exposure technique for films of the thorax through the lungs may be summarized as follows:

For postero-anterior and antero-posterior exposures of the thorax of adult persons:

Distance 35 inches
Milliamperes 30 for one-half second, or
Milliamperes 60 for one-fourth second
Voltage appropriate for the thickness from the thickness-voltage chart.

Distance 48 inches
Milliamperes 100
Time one-tenth second
Voltage from the chart plus 7 to 10 peak kilovolts.

Distance 48 inches
Milliamperes 100
Time one-twentieth second
Voltage from the chart plus 20 peak kilovolts.

Distance 60 inches
Milliamperes 100
Time one-tenth second
Voltage from the chart plus 15 peak kilovolts.

Distance 72 inches
Milliamperes 100
Time one-tenth second
Voltage from the chart plus 20 peak kilovolts.

For oblique views through the thorax use double the time, the other factors as for the antero-posterior views.

For lateral or transverse views of the thorax, multiply the time by 4, the other factors as for the antero-posterior views.

For films of the thorax with a Potter-Bucky diaphragm, select the factors for a similar view without the diaphragm and multiply the time of the exposure by 3.

For the lungs of infants and younger children:

Distance 35 inches
Milliamperes 100
Time one-tenth second
Voltage for 16 centimeters from the thickness-voltage chart.

For lateral films add 10 peak kilovolts.

EXPOSURE COMBINATIONS FOR FILMS OF THE HEAD.

The density to Roentgen-rays of parts of the head, especially through the skull, is not only greater, but it also varies more at different ages than that of any other part of the body. There may be at least two causes for the relatively greater density. One of these may be the bone of the skull. In either the antero-posterior or lateral direction, Roentgen-rays must pass through four layers of compact bone, the inner and outer tables of the skull on both sides. In examining dried skulls some will be found with relatively thin bone; in others the bone is much thicker. In none does it appear to be as thick or as dense as in the shafts of some of the long bones, the femur for example.

The marked differences in the thickness of the bone of different skulls do not produce as much difference in the density to Roentgen-rays as one would expect, and the fact that the total thickness is less than that of other bones leads to the belief that there may be another and more important cause for average head density. This may be due to the presence of the cerebrospinal fluid, to the large quantity of blood in the cerebral vessels, or to some cause within the brain itself.

Variations in the density of the tissues of the head at different ages are quite marked. The density is least in infancy and early childhood, gradually increases as age advances, is at its maximum during adult life, and probably slightly decreases during old age. This variable density due to age probably is caused by differences in the calcium content of the bones of the skull.

The variations in the density of parts of the head control the selection of exposure factors for films through this region. While the density is least in infancy and early childhood and gradually increases, it has been found that the latitude in Roentgen-ray films permits of the use of a few combinations of exposure factors for roentgenography of the head. Selecting a voltage based on the thickness from the thickness-voltage chart, the required intensity of the rays will need to be varied from one that is equal to that given in the basic technique to one that is twice as great.

For the heads of infants and very young children, the intensity should be equal to that given in the basic technique. For the heads of older children (from two to twelve or fourteen years of age) in the transverse direction, the intensity should be one and one-fourth that of the basic technique, and for films in the antero-posterior direction it should be one and a half times as great. For films of the heads of children after puberty and of adults in the transverse direction, the intensity should be one and a half, and in the

antero-posterior direction it should be twice that given in the basic technique.

Taking the voltage according to the thickness as given in the thickness-voltage chart and the different intensities of rays required by different ages, it is relatively easy to devise sets of exposure factors suitable for roentgenography of the head. Since many views through the head are made neither in the direct antero-posterior, postero-anterior, nor lateral directions, as in nasal accessory sinus, jaw, and mastoid films, in selecting the voltage it is especially important that the measurements of the thickness be in the line that will be traversed by the central rays from the tube and of the thickest portion through which the rays must pass. Such measurements can be made more accurately with a pelvimeter or special measuring instrument than with a ruler.

To diminish distortion in exposing films of the head, a constant distance of 35 inches should be used. With this distance the different intensities may be obtained by varying the time of the exposures, the milliamperage, or the voltage. Fifty milliamperes for two seconds or 100 milliamperes for one second will give an intensity similar to that of the basic technique, suitable for parts of the heads of infants and very young children. For lateral views of the heads of older children 50 milliamperes for two and one-fourth seconds may be used. For antero-posterior films of the heads of older children 50 milliamperes for three seconds will be correct. For films of the heads of children after the age of puberty and for those of adults, 30 milliamperes for five seconds may be used for films in a lateral direction. For films in an antero-posterior direction 50 milliamperes for four seconds, or 20 milliamperes for five seconds with the addition of 10 peak kilovolts will be correct.

The use of the Potter-Bucky diaphragm in head roentgenography is largely a matter of personal choice. In roentgenograms for the detection of injury and for the examination of the cranial contents, the diaphragm is preferable. For the examination of the nasal sinuses, mastoid regions, optic foramina, etc., films without the diaphragm are preferred by many.

Distortion on head roentgenograms made with a diaphragm is quite marked if less than a 30-inch anode-grid distance be used. A distance of 35 inches will give distinctly less distortion than the shorter distance. At a 35-inch distance enough voltage must be added to the factors given for films without the diaphragm to compensate for absorption by the grid. This will be found to average about 10 peak kilovolts.

The proper groups of exposure factors as indicated in the preceding paragraphs may be summarized as follows:

1. For lateral or transverse and antero-posterior views of the head of an infant or very young child:
   Distance 35 inches
   Milliamperes 50
   Time two seconds or
   Milliamperes 100
   Time one second
   Voltage from the thickness-voltage chart.

2. For lateral views of the head of an older child:
   Distance 35 inches
   Milliamperes 50
   Time two and one-fourth seconds
   Voltage from the thickness-voltage chart.

3. For antero-posterior films of the head of an older child:
   Distance 35 inches
   Milliamperes 50
   Time three seconds or
   Milliamperes 30
   Time five seconds
   Voltage from the thickness-voltage chart.

4. For lateral films of the head of a child after the age of puberty or of an adult:
   Distance 35 inches
   Milliamperes 30
   Time five seconds
   Voltage from the thickness-voltage chart.

5. For antero-posterior or postero-anterior films of the head of a child after the age of puberty or of an adult:
   Distance 35 inches
   Milliamperes 50
   Time four seconds
   Voltage from the thickness-voltage chart, or
   Distance 35 inches
   Milliamperes 20
   Time five seconds
   Voltage from the thickness-voltage chart plus 10 peak kilovolts.

6. For the exposure of films of the head with a Potter-Bucky diaphragm use the other factors for the age and view as given above and add 10 peak kilovolts.

While these combinations of exposure factors for films of the cranium are based on the thickness-voltage chart and have been found entirely satisfactory, an alternate procedure, and one that probably is widely practiced, is to determine from actual exposures combinations of factors that give good films. A reference table is made from these and used for future exposures. In this table would be factors for the different exposures of the films of the craniums of infants, young and older children, and for those of adults. The craniums of adults may be divided into small, medium-sized, and large. These combinations may include those for exposures both with and without the use of a Potter-Bucky diaphragm or wafer grid. A partial table of this kind is the following:

For lateral exposures of the craniums of older children and adults:
Constant factors:
Distance 35 inches
Milliamperes 30
Par-speed screens.

	Voltage	
	Without diaphragm	With Potter-Bucky diaphragm
Small	48	55
Medium-sized	50	58
Large	52	60

For films of the nasal accessory sinuses:
Constant factors:
Distance 35 inches
Milliamperes 30
Hi-speed screens.

	Voltage					
	Without diaphragm			With Potter-Bucky diaphragm		
	Waters	Caldwell	Granger	Waters	Caldwell	Granger
Small	55	55	52	68	65	60
Medium-sized	60	57	55	70	68	63
Large	63	60	57	73	70	65

SOFT TISSUE ROENTGENOGRAPHY.

In recent years considerably more attention has been given to roentgenographic examinations especially to show the soft tissues of the body, such as muscles, blood-vessels, tendons, newly-formed callus around fractures, soft tissue tumors, etc. The principle upon which soft tissue roentgenography is based is the use of as low a voltage through the tube as possible, compensating for the low voltage by increasing the milliampere-seconds of the exposures. The common procedure seems to be to use from 250 to 300 milliampere-seconds obtained by 100 milliamperes for two and a half or three seconds, or 50 milliamperes for five or six seconds. The voltage

is reduced accordingly. The required voltage reduction is somewhat variable, being most often 5 to 10 peak kilovolts. In extremities, to show the skin and subcutaneous tissues, the voltage reduction is 2 to 4 kilovolts greater than if the muscles, deeper vessels, and periosteum are to be shown. On such roentgenograms the osseous structures are underexposed.

The same basic principle of soft tissue roentgenography also can be used for exposures of other parts of the body, the gall bladder and the kidneys for example. For such the Potter-Bucky diaphragm may be used, the changes from the usual conforming to the laws and experiences governing x-ray exposures. A satisfactory modification of the usual Bucky exposure would be to use an anode-film distance of 25 inches, 300 milliampere-seconds (100 milliamperes for three seconds) with the voltage from the thickness-voltage chart minus 10 peak kilovolts.

For the soft tissues of the extremities it has been recommended that the filter be removed from under the tube and one intensifying screen instead of two be used. The filter absorbs some of the softer rays, and the top intensifying screen more than offsets its fluorescent action by absorption of rays. The time-temperature method of development of films is not recommended, the development being carried out by sight.

By the proper adjustment of milliampere-seconds and voltage, many soft tissue structures can be shown that are not apparent on the usual routine roentgenogram.

SELECTION OF EXPOSURE COMBINATIONS.

The exposure combinations given in this chapter have been more or less arbitrarily grouped under five headings. This is not intended to indicate that the combinations given in each group should only be used for exposures of films of parts of the body for which that group was primarily designed. The combinations in the first group, those for the extremities, may be used for any parts of the body that are of average density. These include the extremities, the shoulders the hips, the neck, and the abdomen. Similarly those combinations for films of the abdominal viscera also may be used for the same parts as those of the first group.

In exposing films of the abdominal viscera with a Potter-Bucky diaphragm, as the kidneys and gall bladder for example, the factors would be selected from those for use with the diaphragm and not from those for the abdominal viscera. The exposure combinations for the thorax through the lungs are intended primarily for films of the lungs, but they serve as well for films of the ribs above the diaphragm and for those portions of the mediastinum the delinea-

tion of which depends on the contiguity of the air-filled lungs. Oblique and lateral views of the sternum and thoracic vertebræ take the same exposure factors as similar views of the lungs, but the ribs below the diaphragm and antero-posterior views of the thoracic vertebræ require the same combinations as films of the abdomen, either with or without a Potter-Bucky diaphragm. Exposures of the mandible take the same combinations as do those of other parts of the head.

The different groups include more than forty combinations of exposure factors. Familiarity with all of them is not necessary for satisfactory roentgenographic work. A few, probably less than one-fourth, will be practically all that are required even in a busy laboratory. The beginner especially is cautioned to work with as few of them as possible. One combination for films of the extremities, one combination for films of the abdominal viscera without a Potter-Bucky diaphragm, except the stomach, and one for the stomach, one or two for films with a Potter-Bucky diaphragm, one for films of the lungs of an adult, one for films of the lungs of infants and children, and those for films of the head will fulfill almost all requirements.

If dependence be placed on a suitable thickness-voltage chart for the selection of the proper voltage, remembering the distances, milliamperages, and exposure times for so few combinations will be easy. In becoming conversant with these combinations, it may be advisable to copy them on a piece of paper and post them, with the thickness-voltage and other charts and tables, near the control panel of the machine with which they are to be used. By so doing they may be referred to quickly at any time. Then as experience increases, other combinations may be added which will give a greater latitude in the selection of factors for different roentgenographic exposures.

CHARTING EXPOSURE FACTORS.

Occasions may arise when it is desirable to make a chart for certain kinds of roentgenographic exposures using some out-of-the-ordinary combination of exposure factors. Usually these combinations have one variable factor with the others kept constant. This variable factor is most often the voltage through the tube or the time of the exposure. By experiences from actual diagnostic exposures, a chart may be constructed to be used in future work.

As an illustration of the method of making such a chart, suppose one is to be made for use with a cystoscopic table equipped with a Potter-Bucky diaphragm using a unit type machine furnishing a voltage equivalent to a 5-inch spark gap and 30 milliamperes of current. The anode-grid distance is fixed at 30 inches. High speed

intensifying screens are to be used. With conditions as outlined, the most desirable technique is one with the time varied to suit the thicknesses of the patients' abdomens.

For such a chart take a piece of plotting paper, mark the ordinates along the left margin as exposure time in seconds and the abscissæ along the bottom as centimeters of thickness (Fig. 58). When the first patient is examined, measure the thickness of the abdomen, select the time thought to be most appropriate for the thickness, and mark a dot on the chart at the crossing of the ordinate for that exposure time with the abscissa for that thickness. When the film has been developed, study it for density and contrast. If it be found to be of satisfactory quality, the dot may be surrounded by a

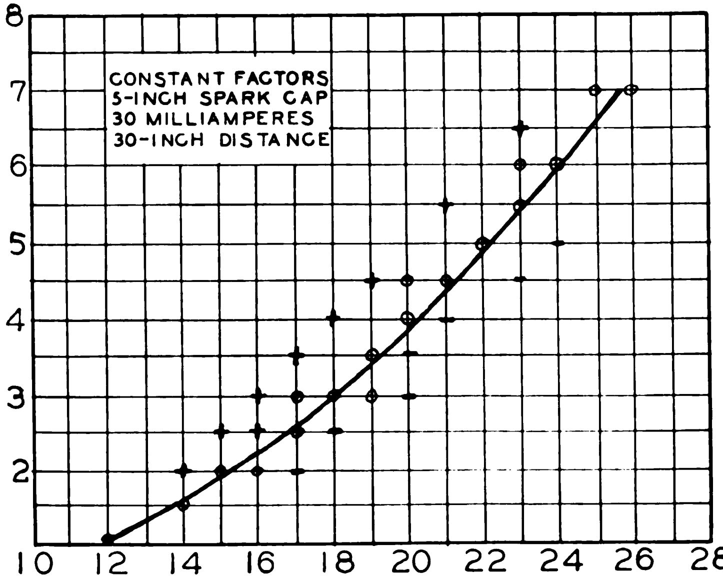

FIG. 58.—A chart made by charting diagnostic exposures in an x-ray laboratory; additional explanation given in the text.

circle; if it be found overexposed, the dot may be replaced by a plus sign; if underexposed, by a minus sign.

This should be done for each patient examined. Soon a number of entries will be made on the chart. Some of these will indicate under- and overexposures, but the most of them will be correct exposures along a curved line following upward from lesser to greater thicknesses and from shorter to longer exposure times. Even a few correct exposures will indicate the trend the line is taking, enabling the selection of the correct exposure times for the others with little opportunity for error. When enough satisfactory exposures have been entered on the chart, the dots surrounded by circles may be connected by a curved line and the chart is complete.

This method may be used in charting any sort of an exposure in which one factor, either time or voltage, is varied to suit the thickness of the part. If the voltage be the variable factor, it may be expressed and entered as ordinates on the chart as peak kilovolts, spark gap in centimeters or inches, voltmeter readings, or even autotransformer control settings. When voltage is used as the variable, the other factors are kept constant. Time of exposure may also be used as the variable factor as in the illustration given above.

This method of charting is very useful when but a single combination of exposure factors is to be charted. If based on exposures of parts of the body of average density, it can be used instead of experimental exposures through paraffin blocks in making a thickness-voltage chart like Fig. 52. It can be used for all the common combinations of factors used in general diagnostic work. However, when this is attempted, a number of charts must be made, one for each combination. The perfection of a basic technique and its modifications, used with a thickness-voltage chart, is much simpler, does not require so much work, and is much more elastic in its use.

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CHAPTER XI.

ROENTGENOGRAPHIC TECHNIQUE WITH THE UNIT TYPE MACHINE.

IN the unit type are included all those x-ray machines which do not have a mechanical or valve-tube rectifier, but which depend on the x-ray tube for the rectification of the secondary current. As explained in Chapter II, all radiographic x-ray tubes, except the universal type Coolidge tubes, have the power of suppressing half the waves of a high-voltage alternating current permitting the opposite half waves to pass for the production of Roentgen-rays. In doing this, there is more strain on the tubes than when rectified current is used, reducing to a lower limit the voltage and milliamperage that may be impressed on the tubes. These limits are given on the energy rating chart that should accompany each tube.

Unit type x-ray machines are not as complicated nor as expensive as the larger type. This probably accounts for the larger number of different models that have been produced. Because there are so many kinds of unit type machines, it is quite impossible to devise a roentgenographic technique that is applicable to all of them. The differences between the two types, an explanation of the operating characteristics of unit type machines, a discussion of the kind of roentgenographic technique that is required with them and especially the description of a method of developing such a technique are all that can be included. Since much that is applicable to all roentgenography, given in Chapters VI, VII, VIII, IX, and X, cannot be repeated, these should be studied as an introduction to this chapter.

The chief differences between the transformer type of x-ray machine equipped with a rectifier and the unit type are the smaller size and capacity of the latter and the fact that a spark gap cannot be used for directly measuring the voltage in the secondary circuit. Usually the capacity of machines of the unit type is limited by that of the tubes used with them, the machines being designed to suit the tubes. This varies from 63 peak kilovolts and 10 milliamperes for the oil immersed dental and portable units to 90 kilovolts and 30 or more milliamperes with some of the larger units.

With unit type machines the voltage of the inverse current (the suppressed half of the high-voltage waves) is higher than that of the half waves that pass through the tube. This makes impossible the

testing of the voltage through the tube by means of a spark gap of any kind. To replace an accurate calibration, quite often the primary voltmeter is calibrated by the manufacturer so that a certain voltmeter reading will give a definite peak kilovoltage or spark gap through the tube, or the multiple-pole switches of the autotransformer are fitted with illuminated dials that serve the same purpose. Even when the machine is so constructed, it is advisable to depend more on tests of photographic effects of different machine settings than on the control settings.

Some unit type machines are not provided with a voltage control in the primary circuit, there being but one secondary voltage available for use. If a voltage control be provided, it is usually a small autotransformer. These have different steps in different models. A common form has 3 voltage steps, those which presumably give a voltage equivalent to a 3-, 4-, and 5-inch spark gap in the secondary circuit and a small autotransformer with 10 steps of 2 to 4 volts each to adjust the voltage. Other forms of autotransformers are also supplied. Machines of more recent manufacture have as many as 14 to 20 steps in the autotransformer, giving intervals of 2 to 3 kilovolts in the secondary circuit. Others have secondary voltage intervals as small as 1 peak kilovolt.

Each unit type machine is provided with an alternating current voltmeter in the primary circuit or has illuminated dials attached to the multiple-pole autotransformer switches. The voltmeter either measures the voltage of the current passing into the autotransformer or that passing from the autotransformer to the high-tension transformer. The second is the more common form. The voltmeter and illuminated dials have the same use as in larger machines. They serve as the only indicators of the voltage of the secondary current and therefore as the only indicators of the quality of the resultant rays.

In roentgenographic work with a unit type machine the laws which govern roentgenographic exposures, as explained in Experiments, 4, 5, and 6, Chapter VI, are usually applicable. With the other factors constant, the photographic effect of different exposures varies directly as the milliamperage of the current through the tube, and directly as the times of the exposures. With the other factors constant, the intensity of an exposure varies inversely as the square of the anode-film distance. The charts showing modifications of exposures necessary for changes in distance (Figs. 48 and 49) may be used with unit type machines. However, the chart showing changes in exposures necessary with changes in the voltage of the secondary current (Fig. 51) is not always applicable. Since the technique developed with the unit type machine may include all possible

voltage and milliamperage variations, the use of a chart for this purpose is sometimes unnecessary.

The operating characteristics of the unit type machine are much the same as those of larger machines. For instance, with a particular milliamperage, a certain voltmeter reading and control setting in the primary circuit will give a constant kilovoltage through the tube. If the milliamperage be changed the voltage will either rise or fall, depending on whether the milliamperage is increased or decreased. To keep the secondary voltage constant with a change in milliamperage, the primary voltage must be changed by the autotransformer before the exposure begins, so that the voltmeter readings during the exposures will be the same.

Table XI.

	Milliamperes.		
Spark gap	10.	20.	30.
3	120	127	140
4	123	127	140
5	125	132	140

Table XI.—This table shows the voltmeter readings on a unit type machine that are required with each of the three voltage steps, with the three milliamperages, to give a constant voltage through the tube during the exposures.

This is illustrated in Table XI. The voltmeter readings were obtained from the same machine used in making the chart shown in Fig. 59. That the secondary voltages may be constant at the different milliamperages with each of the three spark-gap settings, on this machine the voltmeter must read 115 volts during the exposures. Meter readings before the exposures begin, for the different milliamperages, are not the same. For example, with the setting for the 3-inch gap, with 10 milliamperes, the reading is 120 volts; with 20 milliamperes, it is 127 volts, and with 30 milliamperes, it is 140 volts. If this precaution be not observed, changing the milliamperage will give different secondary voltages, producing rays of different penetrability, requiring a change in the time of the exposures. Unless the voltage change is compensated for by a higher or lower primary voltage, since the voltage is not constant, the law that the photographic effect varies directly as the time of the exposure and as the milliamperage will not apply.

In developing a technique for use with the unit type machine, the principles with reference to the development of a basic technique as given in Chapter VII should be followed, modified to meet the limitations of this type. The selection of the exposure factor to be most often varied depends on the number of voltage steps in the autotransformer. With machines having 14 to 20 or more steps, thus giving a sufficient number of secondary voltages, the voltage

may be made the chief variable factor and a thickness-voltage chart prepared (Chapter VIII). For those giving secondary voltage selections greater than 2 or 3 peak kilovolts, especially those types with three voltages, the time of the exposure must be the chief variable factor. For those with a single voltage it may be necessary to vary both the time of the exposure and the anode-film distance.

An exposure chart, answering the same purpose as the thickness-voltage chart for larger machines, and from which the sets of exposure factors may accurately be selected before an exposure begins, can be made for the unit type. In all such charts the different thicknesses of the parts of the body to be examined should be the basis for the different groups of exposure factors. A chart of this kind, made for a unit type machine with three voltage selections, is shown in Fig. 59.

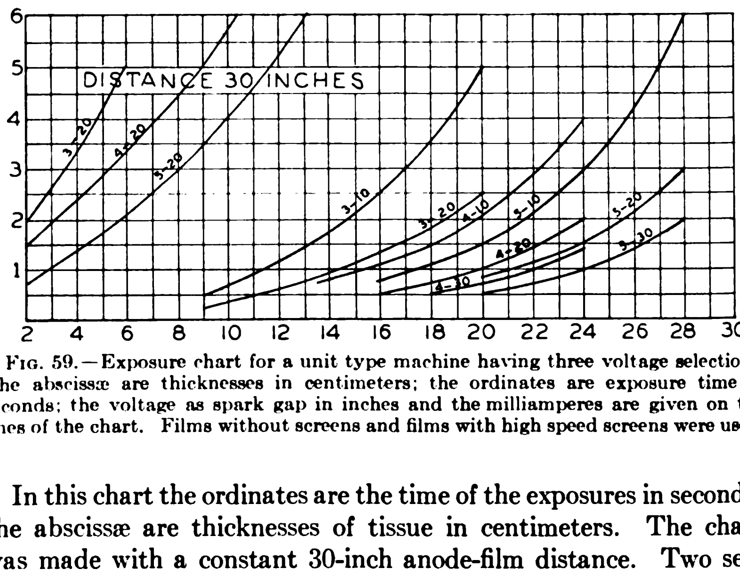

FIG. 59.—Exposure chart for a unit type machine having three voltage selections. The abscissæ are thicknesses in centimeters; the ordinates are exposure time in seconds; the voltage as spark gap in inches and the milliamperes are given on the lines of the chart. Films without screens and films with high speed screens were used.

In this chart the ordinates are the time of the exposures in seconds; the abscissæ are thicknesses of tissue in centimeters. The chart was made with a constant 30-inch anode-film distance. Two sets of lines are included: one for films without screens for parts from 2 to 10 centimeters in thickness and one for exposures of thicker parts using high speed intensifying screens. To give as much versatility as possible to the selection of appropriate sets of exposure factors for different thicknesses, 10 and 20 milliamperes are included for the 3-inch gap, and 10, 20, and 30 milliamperes for the 4- and 5-inch gaps. From one to as many as five or more different combinations of milliamperage, voltage, and time for each thickness are given on this chart, each combination giving films of approximately the same density. Of course, the use of any other type of intensifying screens would require a similar chart having much the

same appearance but with different combinations of factors for the different thicknesses.

An exposure chart can be made for any model of unit type machine. A somewhat different kind would be required for each model. For example, for a machine equipped with a 10-milliampere tube with three voltages, the chart could be similar to the one in Fig. 59, omitting the lines for 20 and 30 milliamperes. For one with a single secondary voltage, a longer distance would need to be used for the thinner parts, but the three milliamperages could be retained. For a machine with more than three voltages, the voltage could be made the variable factor within the voltage limits; either above or below these limits, as necessary, the time could be changed, using the highest for the greater thicknesses with an increasing exposure time and the lowest voltage for the lesser thicknesses with a decreasing time. Only a little ingenuity should be required to devise a chart suited to the peculiarities of any other model.

There is no way of devising a chart or perfecting a particular form of technique that is applicable to even a major portion of unit type machines as can be done for the larger. Neither can exposure factors known to give good films on a large machine always be used with good results on the unit type. Although the statement has been made that the roentgenographic results are the same with similar exposure factors on the two types of machines, this has not always been found to be correct. On some of the older forms—those with three voltages—the Roentgen-ray output seems to be less than with the larger machines. On one new unit type machine having steps of 1 peak kilovolt in the secondary circuit, the output is definitely greater than on a similar larger machine. An explanation of these variations will not be attempted.

Since it is highly improbable that one will be able to transfer satisfactorily a set of known exposure factors for a large machine to one of the unit type or to use with success a chart on one unit type machine that was devised for another, a chart is required for each unit type equipment. The only way that this can be done quickly and satisfactorily is by means of experimental exposures through paraffin blocks. It is not even possible to outline a set of experiments for this purpose as was done in Chapter VIII for the thickness-voltage chart. With a set of paraffin blocks one must depend on one's own ingenuity in planning and performing the experiments, in selecting the constant and variable exposure factors, and in working out the chart for use with the machine. The experience gained by so doing will more than compensate for the expense, the time, and the effort required.

While exposure charts for unit type machines can be made more

easily and quickly by experimental exposures through paraffin blocks, it also is possible to make them by charting the results of exposures made in the laboratory. By adapting the directions for charting exposures given on page 186 to the peculiarities of the unit type machine and by carefully recording all exposures, whether correct, under- or overexposed, an exposure chart can be made. In fact, the chart shown in Fig. 58 as an example of charting exposures was made in a urographic room with the same machine used in making the chart in Fig. 59.

When a chart has once been perfected, by making changes in the different exposure factors according to the laws governing roentgenographic exposures and making the changes known to be required for films of the thorax, for films of the skull, and for exposing films with a Potter-Bucky diaphragm, all other required exposure technique possible with the unit type can be derived from it. To illustrate the ways in which this may be done, the sets of exposure factors for different regions of the body indicated in the following discussion, based on the chart in Fig. 59, are included as examples.

For films of any part of the extremities, the factors appropriate for the thickness as taken directly from the chart may be used. When immobilization can be secured, it is preferable to use the lowest voltage with the longest exposure time. This will give films of maximum contrast. The chart gives eight different combinations of time, milliamperage, and voltage that may be used for a part 20 centimeters thick. The best films would be obtained with one of those using the 3-inch gap; higher voltages and shorter exposure times are used only when immobilization is uncertain.

With high speed intensifying screens and a unit type machine producing 85 peak kilovolts or its equivalent, with 30 milliamperes, very satisfactory roentgenography of the abdominal viscera can be done. Except those of the stomach, films of the abdominal viscera should be exposed in two and a half seconds or less. This includes films of the gall bladder, liver, appendiceal region, colon, and urinary tract.

Peristaltic motion of the stomach usually will blur films made with an exposure time of more than one second; whenever possible a half second exposure is preferable. The chart in Fig. 59 with this particular unit type machine shows that films of the stomach in an abdomen that is 20 centimeters in thickness can be made in a half second, and even those in an abdomen 24 centimeters thick can be made within the one-second limit. It is unusual for an abdomen to be encountered that is more than 24 centimeters in thickness.

The absorption of Roentgen-rays by the lead strips of the grid

of a Potter-Bucky diaphragm increases considerably the quantity of rays required for satisfactory films. Experience leads to the belief that absorption by grids of different models is about the same. With the other factors constant, the absorption of the grid of a diaphragm requires that the exposure time, selected from the chart as appropriate for the thickness of the part, be multiplied by 3 to give films of good quality. If this should not be found correct, it will be necessary to experiment with actual exposures, either with patients or through paraffin blocks, to determine the correct modifications.

With the same voltage and distance films of the thoraces of adults require approximately one-seventh the quantity of rays necessary for other parts of the body of the same thickness. Such films should be made with the longest practicable anode-film distance. With the unit type machine this should be 35, 48, or 60 inches. To modify the exposure from a chart like Fig. 59, first multiply the number of milliampere-seconds for the same thickness from the chart by a factor to compensate for the increased distance (Experiment 5). With a chart made at a 30-inch distance, this is 1.33 for a 35-inch distance, 2.5 for a 48-inch distance, and 4 for a 60-inch distance. Then divide the number obtained by 7, because films of the thorax of adults require one-seventh the quantity appropriate for the same thickness of another part of the body.

For example, from Fig. 59 it is found that using a 4-inch gap and 10 milliamperes the time required for 20 centimeters thickness is two seconds or 20 milliampere-seconds. Multiplying 20 by 2.5 gives 50, dividing by 7 gives approximately 7 as the number of milliampere-seconds (30 milliamperes for one-fourth second) to be used in exposing a film of a thorax that is 20 centimeters thick, using a 4-inch gap at a 48-inch distance. In the same manner 11 milliampere-seconds (22 milliamperes for a half second) are found to be appropriate for a thorax of the same thickness at a distance of 60 inches. The voltage through the tube must not be changed. This means that when making a chest exposure the voltmeter should read the same as during the exposure used in making the chart. By using this rule, a reference table can easily be made that will give the number of milliampere-seconds for thoraces of different thicknesses, at different voltages, at any distance.

It must be remembered that films of the thoraces of infants and young children, for reasons given on page 179, require a proportionately greater voltage or a longer exposure time than do those of adults. Since the exposure factors for this purpose are relatively constant irrespective of the size or age of the infant or child, when

by trial exposures they once have been determined, they may be used for each succeeding similar examination.

The variations in the density for Roentgen-rays of parts of the head require a special exposure technique for films of this region (see page 181). Using a voltage based on the thickness and obtained from an exposure chart like Fig. 59, for satisfactory films the intensity must be increased to as much as twice that given by the chart. With unit type machines this can best be secured by appropriate increases in the exposure time. The required changes are as follows: (1) For lateral or antero-posterior views of the heads of infants and very young children an increase is not necessary. (2) For transverse views of the heads of older children the time should be increased 25 per cent; for antero-posterior views the time should be increased 50 per cent. (3) For transverse views of the heads of children after puberty and of adults the time should be increased 50 per cent; for antero-posterior views it should be doubled. In measuring the thickness to select the voltage, precautions given on page 182 should be observed.

CHAPTER XII.

MISCELLANEOUS INSTRUCTIONS.

In selecting the size of film to use, in posing patients, and in making x-ray exposures, there are many general precautions that should be observed. For convenience these are grouped together and included in this chapter.

SIZE OF FILMS.

The film used for any x-ray examination should be large enough adequately to include the region to be examined, but for the sake of economy in materials it should not be much larger. The size of the part being examined and the exactness with which the disease can be located should control the size of the film. For example, a Colles' fracture can be so definitely located that a 6½- by 8½-inch film is large enough for making two views of the injury. On the other hand injuries of the pelvis can rarely be definitely located either by the patient or the examiner; they are apt to be multiple and widely separated, requiring films large enough to include the entire pelvis and the upper ends of both femora.

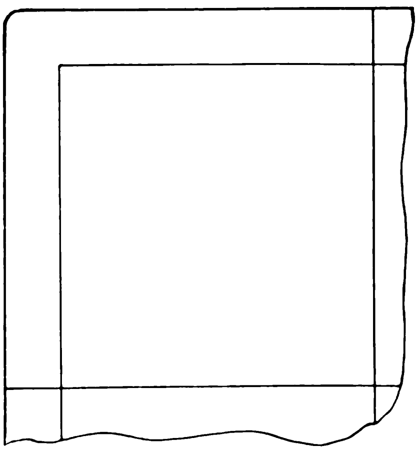

Fig. 60.—Scratch marks on the surface of a cassette over the margins of the film and dividing the film into halves both longitudinally and transversely.

In selecting a film to be used for any purpose, ample allowance must be made for distortion in size. For small parts close to the surface of a cassette this is not marked, but for large parts, especially if removed from the surface of the cassette, the increase in the size of the image is considerable. Also it increases with the size of the part being examined and the size of the film and is most marked on films exposed with a Potter-Bucky diaphragm. For large parts, such as a thick shoulder or hip, in order to be certain that the whole part will be on the film, the margin of film projecting beyond the part

should be quite liberal, about 2 inches without and 3 inches with a Potter-Bucky diaphragm.

When using films in cassettes, allowance must be made for the projection of the surface of the cassette beyond the margins of the film. This varies with the kind of cassette being used. On some it amounts to $\frac{3}{8}$ inch; on others it is as much as $\frac{3}{4}$ inch. It is a good practice to make scratch marks on the face of all cassettes parallel with the sides and ends and exactly over the margins of the film (Fig. 60). If this be done, the exact film size will be shown on the face of the cassette and allowance can be made for the difference in size between the film and its container.

POSITION OF THE IMAGE ON THE FILM.

Even if the roentgenographic quality of films be good, their appearance can be seriously impaired by the position of the images on them. If an image extends obliquely so that a film must be placed on one corner in order to examine it, that film is not as satisfactory nor can it be examined as easily as one in which the chief lines of the images are parallel with the film margins. Long bones should be shown with their long axes parallel with the sides or ends of the film; parts of the trunk should have the median plane, the vertebral column, or the side of the trunk parallel with the film margins; the basal part of the skull should be parallel with the side of the film; even an image of the foot should have the mesial margin or the sole parallel with one side or end of the film. Observing this precaution is essential if the best appearing films are to be produced.

POSITIONING OF THE X-RAY TUBE.

There are a few precautions that should be observed in positioning the *x*-ray tube for exposures, particularly if a tube with a line or band focus be used. Such a tube housed in a lead glass bowl or globe may turn in its housing. This will cause an enlargement of the effective focal spot and decrease detail on films exposed with it in this position. To obtain full value of the smaller effective focal spot in a tube of this kind, unless for some special reason an oblique exposure is being made, the focal spot and the cathode filament should always be perpendicular to the film surface.

In the exposure of small film areas the distribution of the *x*-rays and the detail on the films will be uniform over the whole area. When larger film areas are used, there will be some differences. That portion of the film under the anode end of the tube will show better detail than that under the cathode end. This is because the effective focal spot becomes smaller toward the anode and larger

toward the cathode end of the tube. This is sometimes called the heel effect of the tube.

There is also a somewhat similar difference in the quantity of the x-ray delivered at different angles from the focal spot of the tube. There will be appreciably more radiation toward the cathode than toward the anode end. This can be of use in the exposure of large films. If there be a difference in the thickness or density of the part of the body being exposed, it is advantageous to have the cathode end of the tube over this portion, or with the anode end pointing toward it. If this be done the greater intensity of x-rays will be delivered to the thicker or denser part of the body, thus assisting in the equalization of the radiation over the whole film area.

For example, there is less air in the apical portions of the lungs and the muscles over the upper part of the chest increase its density. For these reasons, the cathode end of the tube should be over the upper part of the thorax in lung exposures. In lateral exposures of the lumbar vertebræ the cathode end of the tube should be over the lower part directing the greater intensity of x-rays into the thicker lower portion. In postero-anterior exposures of the abdomen of a thin person with thick hips, the lower part of the abdomen may be considerably thicker than the upper part. Exposures with the anode and of the tube over the lower thicker part will partially equalize the exposure over the whole film area. When other exposures are made the arrangement of the tube in this regard will be apparent to anyone keeping these facts in mind.

NUMBER OF EXPOSURES.

The number of exposures that should be made in any examination varies with the region and the nature of the condition being studied. Enough should be made to show adequately, usually in different projections, the structures in question. Holmes and Ruggles say that "A roentgenogram showing only one view is an isolated observation, and is to be relied upon less, perhaps, than a single observation in any other branch of medicine." This statement probably is exaggerated for emphasis, yet in many instances it is literally true.

Expecially in making an examination of a part to detect bone injury or disease, at least two exposures as nearly as possible at right angles to each other should always be made. One who has examined many roentgenograms of fractured long bones knows that fragments appearing to be in perfect position on one view may be shown to be widely separated on a view made at right angles to the first and that occasionally a fracture is seen on one view and not on the other. These two views can be made on one film if it

be large enough by covering half the cassette with a piece of lead or lead rubber while the other half is exposed. To aid in making such exposures, scratch marks on the surface of the cassettes, accurately dividing them into equal parts both longitudinally and transversely, will be found helpful (Fig. 60).

In securing two views of an injured extremity it usually is possible to turn the part through the required angle of 90 degrees. Occasionally, as in case of a fracture of the shaft of the femur, turning the part is not practicable. It is then advisable to turn the tube so that the rays are directed horizontally through the part on to a cassette that is standing on edge. The covering material protecting one-half of a film exposed in this manner should be fastened to the cassette with strips of adhesive plaster.

Should a joint be flexed and the examiner not be able to straighten it, a lateral view of the joint and the bones both above and below the joint may be taken. For views at right angles to the lateral view it may be necessary to make two exposures, one of the bone above the joint, and the other of the bone below the joint. Small films or one-half of a medium-sized film may be used for each of these exposures. Considerable manipulation and ingenuity may be required, such as supporting the extremity and cassette at an angle with sand bags or pillows, and tilting the tube at an angle, to obtain the required views of the entire injured region at right angles to each other. An examination cannot be considered complete until this has been done.

In making examinations of injured parts when views at right angles to each other are difficult or impossible to secure, as of the shoulder or hip, stereoscopic films should always be taken. Stereoscopic films should always be made of injuries to the pelvis and of suspected injuries of the vertebral column. Even when it is possible to make a lateral view of the vertebral column, small parts of the vertebræ, the images of which are superimposed, are shown to better advantage on stereoscopic films.

Case emphasizes the necessity of a constant technique in roentgenography of bone and joint lesions and describes the positions and views that should be made routinely of different bones and joints of the body. The number of views required for the complete examination of each part of the body is given in the detailed description of roentgenography of the different regions in following chapters.

DIAPHRAGMING.

By diaphragming is meant the use of cones, or of openings of various sizes in pieces of lead or lead rubber, to limit the rays that strike a part being exposed so that the beam is not much larger than the

film that is used. Proper diaphragming reduces scattered radiation to a minimum, thus giving films of maximum detail and contrast. While it may not be of special importance in exposing films of thin parts with a relatively low voltage, diaphragming is of the greatest importance in making exposures of thick parts without the use of a Potter-Bucky diaphragm or a wafer grid.

It is not a good practice to use a beam of Roentgen-rays that is much larger than the size of the film area being exposed. The size of the beam can be controlled and directed by using cones of various sizes. The area of film that will be covered by each cone in the equipment at the different distances it is used may be determined by measuring the diameter of the area on the table illuminated by the filament when the filter under the tube has been removed. For example, a cone that is 2½ inches in diameter at the small and 3¾ inches in diameter at the large end will give an area of 8 inches in diameter at 25 inches distance and one of about 11½ inches diameter at 35 inches. One should be familiar with the area covered at the different distances and use the cone best suited for the work to be done.

If an assortment of cones suitable for all purposes is not available, diaphragming may be done by inserting in the slot under the tube with the filter a piece of lead with an opening of appropriate size in the center. An assortment of lead diaphragms of this kind suitable for all purposes may be prepared and kept on hand.

In preparing a set of lead diaphragms, first determine the sizes of the film areas and the distances that are used in the laboratory. In our laboratory we found that all possible film areas had been utilized. These include the entire films of all sizes and all sizes exposed one-half at a time, divided both longitudinally and transversely, using 25-, 30-, and 35-inch anode-film distances. In addition, the largest two sizes are used in exposing films of the chest at 48, 60, and 72 inches.

Calculating the diaphragm sizes for each of these areas was not difficult. This was done by the use of simple proportion, anode-diaphragm distance (D) is to anode-film distance (D′) as diaphragm opening (X) is to film area in length or width (L). Using this proportion, a table was prepared showing the size of the diaphragm opening for each of the film areas.

When this table was studied, it was found that a diaphragm suitable for one film size at a distance of 25 inches was suitable for the next larger size at 30 inches, and the next at 35 inches. For example, a diaphragm of 1⅝- by 2⅛-inch size will cover a 6½- by 8½-inch film at 25 inches, an 8- by 10-inch film at 30 inches, and a 10- by 12-inch film at 35 inches. This held true for the areas made

by dividing the films both longitudinally and transversely. By using each diaphragm for as many areas as possible, it was found that, although over 50 film areas were in use, they could adequately be covered by about fifteen diaphragms—those commonly used by

TABLE XII.

Diaphragm No.	Size.	Film areas covered. 25.	30.	35.	Distances in inches. 40.	60.	84.
1	$1\frac{3}{4}$ x $2\frac{1}{8}$	A	B	C	D		
2	$1\frac{3}{4}$ x $1\frac{1}{16}$	A-T	B-T	C-T	..	..	E
3	1 x $2\frac{1}{8}$	A-L	B-L	C-L			
4	2 x $2\frac{1}{2}$	B	C	D	E		
5	2 x $2\frac{1}{4}$	B-T	C-T	D-T			
6	1 x $2\frac{1}{2}$	B-L	C-L	D-L			
7	$2\frac{1}{2}$ x 3	C	D	E			
8	$2\frac{1}{2}$ x $1\frac{1}{2}$	C-T	D-T	E-T			
9	3 x $3\frac{1}{2}$	D	E				
10	$2\frac{3}{4}$ x $1\frac{3}{4}$	D-T	E-T				
11	$3\frac{1}{2}$ x $4\frac{1}{2}$	E					
12	$1\frac{1}{4}$ x $1\frac{1}{2}$	C-$\frac{1}{4}$					
13	$1\frac{2}{5}$ x $1\frac{7}{10}$	..	..	..	..	E	

TABLE XII.—Diaphragm sizes showing film areas covered by each at different distances. A, $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film; B, 8- by 10-inch film; C, 10- by 12-inch film; D, 11- by 14-inch film; E, 14- by 17-inch film; T, films divided transversely; L, divided longitudinally. These diaphragms apply only when the anode-diaphragm distance is 6 inches.

No. 12 is a special diaphragm for exposing one-fourth of a 10- by 12-inch film in a plate tunnel for serial films of the pylorus and duodenum.

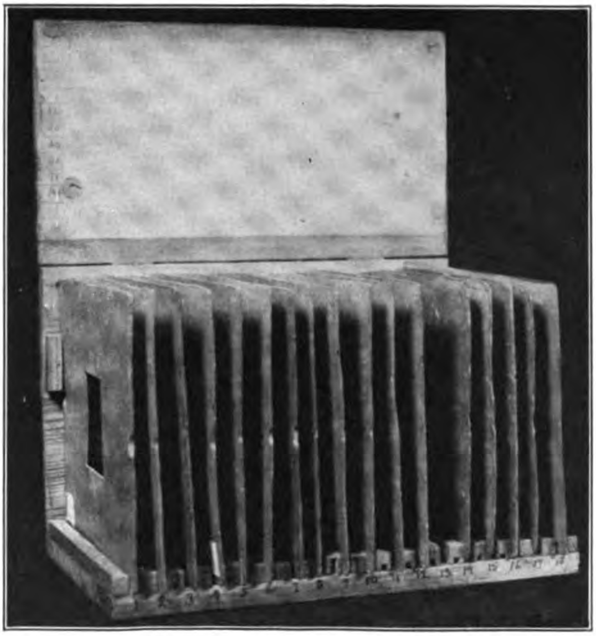

FIG. 61.—A set of lead diaphragms in a slotted box. The film areas covered by each diaphragm are shown in a table similar to Table XII on the lid of the box.

two-thirds this number. When this was known, it was a simple matter to get a piece of sheet lead from the plumber, prepare this series of diaphragms, and make a suitable slotted box for them (Fig. 61). Table XII shows this series of diaphragms and the areas that each covers at the different distances.

Using a diaphragm that exactly covers the film area is more difficult than using a cone. The tube must be exactly centered and the patient carefully posed. By removing an opaque filter or by using a translucent filter, the tube may be centered by the light from the filament. Glass as a filter is as satisfactory as aluminum and may be used in its stead.

The same purpose may be served by covering the part to be exposed with a piece of lead or lead rubber with an opening of proper size in the center. If this kind of diaphragm be used, a cone or a diaphragm of lead may be omitted.

While a Potter-Bucky diaphragm or a wafer grid removes a large percentage of scattered radiation even more is removed by using a cone or a lead diaphragm also, perceptibly improving the results.

IMMOBILIZATION.

The absolute immobilization of a part of the body during an x-ray exposure is of the greatest importance. Not only gross movements but a very slight movement, or even a very fine tremor, will impair or destroy detail on x-ray films. In exposing films of an extremity it is of the greatest importance to have other parts of the body held quiet as well, for movement of any portion will be transmitted to the part being examined. To obtain this degree of immobility, it is necessary that the patient understand that no movement at all is to be made during the exposure. Requesting the patient to keep all parts of the body still usually will accomplish the desired result.

Even if a patient attempts to coöperate in this particular, it often happens that he either is unable to remain perfectly quiet or his intentness defeats its own purpose. This is especially true of those who are in pain from an injury, or of a young patient. To assist in immobilization of a part during an exposure, a number of devices have been described. These include among others a thin board with a round pin in one end to be grasped by the hand while lateral or transverse views of the wrist or forearm are being made, a long board with a short piece at right angles at one end to which the foot may be fastened during exposures of the ankle, leg, knee, or thigh, and clamps for immobilizing the head.

Perhaps the most useful immobilizing device that has been described, and one that can be used for almost any purpose, con-

sists of two sand bags, each weighing 3 to 5 pounds, connected by a long strip of heavy cloth. The cloth should be 10 to 12 inches in width and long enough to allow each of the sand bags to hang over the edge of the table about 2 feet. The sand bags should be as long as the cloth is wide. A light-weight khaki cloth is suitable both for the sand bags and the connecting strip. The sand bags may be placed in pockets in the ends of the strip of cloth and removed when the cloth is laundered. For want of a better name a device of this kind may be called a double sand bag or a weighted bandage (see Figs. 77 and 124).

A double sand bag will fill almost all requirements for an immobilizing device, except those for which a compression band on a Potter-Bucky diaphragm can be used and for immobilizing the kidneys or other viscera during exposures. It may be used for any part of the extremities, or for any part of the head. When not in use, it may be suspended over one end of the table. A laboratory is not quite completely equipped unless it contains at least one double sand bag available for immediate use.

SUSPENSION OF RESPIRATION.

Just as films of an extremity may be blurred by movements, so may films of the abdominal or thoracic viscera be blurred and detail on them destroyed by breathing during exposures. Respiratory movements also will be transmitted to the head, decreasing detail on films of the skull, of the mastoid or nasal accessory sinuses, the jaws, or any other portion. To overcome this difficulty, respiration should be suspended during the exposure of films of these regions.

In order to secure the coöperation of the patient in this particular, it is essential that he be carefully instructed as to what he is expected to do. Time spent in doing this so well that there is no doubt in the patient's mind as to what should be done will prevent making many spoiled and worthless films. In many instances it is even advisable to rehearse with the patient before the exposure is made.

If a patient be simply asked to "hold your breath," almost invariably a rather deep inspiration will be taken before the breath is held. This suffices for films of any part of the skull, but care should be observed not to begin an exposure until after the inspiratory movement is completed and the period of cessation begins.

Exposures of the lungs should be made at full inspiration. Preparatory to making such exposures the patient should be instructed that he will be asked to take in a deep breath and hold it while the exposure is being made. The instructions to the patient should be about as follows: "I will ask you to take in a deep breath, then hold it, and remain perfectly quiet while I make this exposure." Here,

again, the operator must be certain that the inspiratory act has been completed before the exposure is begun.

The cessation of respiratory movements is not nearly so difficult for films of the skull or lungs as it is for films of the abdominal viscera. Slight movement will not affect films of the skull, and exposures of the thorax are usually so short that there is little opportunity for motion, but films of the abdomen are more prolonged so that movements are more likely to occur. For this reason more care is required in instructing the patient when films of abdominal viscera are to be made.

Because the lessened thickness of the abdomen at the end of expiration makes it possible to use a lower voltage through the tube, exposures of abdominal viscera should be made at the end of expiration. There are two methods of proceeding. One, advocated by George and Leonard in exposing films of the gall bladder, is to have the patient breathe quietly until told to hold the breath, which instruction is given at the end of expiration. This is the preferable method when rapid exposures, as those of the stomach, are being made. The other is to instruct the patient to take in one or two deep breaths and then hold the breath at the end of expiration. Each act of this sequence is done at the instruction of the operator. This procedure seems to be the preferable one when longer exposures—from two and a half to five seconds, as when a Potter-Bucky diaphragm is used—are made.

The instructions to the patient in the first instance are something like this: "You must hold your breath while I make this exposure. Just breathe quietly until I tell you to stop, then stop breathing and be perfectly still. Now stop breathing—perfectly still, please." Then make the exposure.

The instructions in the second instance are as follows: "I want you to take in a deep breath and then let it out, then hold your breath while I make this exposure. All ready—now breathe in—now breathe out—now hold your breath—perfectly quiet, please." Then make the exposure.

Occasionally a patient will be encountered, usually one whose comprehension is dulled by illness, or an elderly woman, with whom no amount of instruction nor rehearsal will secure the desired result. Then the best that can be done is to have the patient or an assistant hold the patient's nose during the exposure. Such exposures, as well as those of children whose coöperation cannot be secured, must be made as rapidly as possible in an attempt to diminish by rapidity of exposure the bad effects of motion. This usually means that the voltage must be increased with a resultant decrease in contrast on the complete films.

THE IDENTIFICATION OF FILMS.

An x-ray film should always be marked at the time of exposure so that it can later be identified. Since the films look alike on both sides, this is necessary when parts are exposed that are symmetrical on opposite sides of the body. This applies especially to parts of the skull and the extremities. If films of the nasal accessory sinuses, the mastoid regions, or the jaws be not so marked, the identification of the right and left sides may occasionally be very difficult—instances have occurred when the fillings in the teeth have been used for purposes of identification. It is important that films of injuries be carefully marked, for no one can tell just when one may be called upon to produce and identify the films as a part of medico-legal testimony.

There are several ways of providing for the identification of films. The best of these are methods that provide for marking the films during the exposures or before they are processed. Machines have been perfected that cut figures and letters into thin sheets of metal to be attached to the films or cassettes during exposures. In this way the name of the patient, the date, an identifying number, and other pertinent data will be permanently impressed on the films. A less expensive method is the use of an identification printer. In this method a portion of the film near one corner is protected by sheet lead during the exposure. The name of the laboratory, the patient's name, the date, the number, and other data, typed on a special card or paper, is impressed on the unexposed portion of the film by the printer before the film is processed.

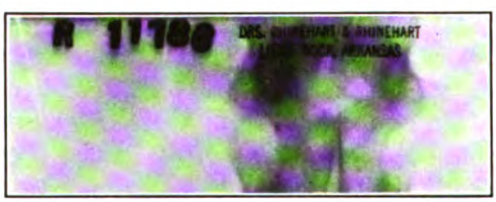

Fig. 62.—Lead figures and name on films for purposes of identification.

Perhaps the simplest method of marking films for identification is by the use of lead numerals and letters and other opaque markers, attached to a piece of adhesive tape and fastened to the exposure holder or cassette during the exposure. These should include an identifying number and the letters R and L to designate the right and left sides of the body (Fig. 62). The date, the view taken, the direction of a stereoscopic-tube shift, and other data may be included in the same way. The number affixed to the films for each patient

should be recorded on an index card, on a copy of whatever report is made of the examination, and on the envelope or folder in which the films are filed.

A simple expedient for determining the right and wrong side of double coated films has been suggested by Cantrell. He had a small rubber stamp made showing his name and address but reading just the opposite from one used for ordinary purposes. With this stamp, using indelible ink, he stamped his name and address on the margin of the intensifying screen nearest the face of the cassette. The ink destroys the fluorescent action of this screen so that the name appears as distinct letters on developed films. The same result can be secured by using an ordinary rubber stamp and putting the name on the screen attached to the lid of the cassette (Fig. 62). While this procedure serves to identify a film as unquestionably coming from a particular laboratory, to complete the identification lead numbers or some other method of identification should also be used.

TIMING EXPOSURES.

If the best results are to be obtained, exposures should always be accurately timed. For exposures of a second or longer, this may be done with a metronome, with the second hand of a watch or clock, or, if practice has made one sufficiently accurate, by counting the seconds. A metronome is preferable to a watch or clock, for the tick of the former can be heard while the latter must be observed, thus taking the eyes of the operator from the apparatus or the patient at a time when either or both should be watched. By practicing counting seconds, many operators have become very accurate. The usual practice is to say, either to one's self or audibly, one-thousand-one, one-thousand-two, one-thousand-three, etc., for as long as the exposure lasts. This method should not be used until practice has developed a sufficient degree of accuracy.

A timing device, commonly called a timer, is the preferred method of timing exposures. In general these devices are of three kinds. The most accurate is an impulse timer which closes and opens the primary circuit of the machine at the no-current interval of the alternating current, usually timing exposures from one one-hundred-twentieth second (a half cycle on 60-cycle current) to one-quarter second (15 cycles on 60-cycle current). Alternating current of another frequency will give other time intervals. These timers cannot be used for longer time intervals than one-quarter second.

Other timing devices provide for time intervals from one-twentieth to as long as thirty seconds. All of these are operated with a synchronous motor (see p. 44) that revolves at a definite speed. By a

system of gears and clutches the timer closes and opens the x-ray switch in the primary circuit of the x-ray machine. A third timing device is a hand timer that operates the x-ray switch by means of a clock mechanism. These provide time intervals from one-quarter to twelve seconds.

The accuracy of these timing devices should not be taken for granted; they should be tested, particularly for the shorter time intervals, before absolute dependence is placed on them. Testing of the longer exposure times, above one second, can be done with the second hand of a watch; testing those less than a second is somewhat more difficult, yet it can be done with considerable accuracy in any x-ray laboratory.

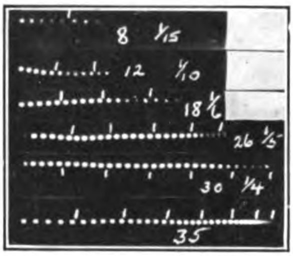

FIG. 63.—Rows of dots made in testing a timer by the method described in the text.

The method usually recommended for this purpose is called the spinning-top method. A top, the essential part of which is a circular piece of sheet lead about 2 inches in diameter with a pinhole near the edge, is spun on the surface of a cassette while an exposure is being made. Since the current through the tube is pulsating and Roentgen-rays are produced by each of the pulsations, if the speed of the top has been appropriate, the developed film will show a black spot for each pulsation. In full rectified current of 60 cycles there are 120 such pulsations per second; with the current from a single valve tube rectifier and a unit type machine there are 60 pulsations per second. By counting the spots on a film exposed in this manner and dividing by either 60 or 120, depending on the type of machine used, the resulting fraction will be the exact time of the exposure. For alternating current of a different number of cycles, the number of spots will, of course, be different.

The difficulty with the spinning-top method is in making the exposure when the top is revolving at an appropriate speed. A method that is simpler, but one which is used in the same way, is the use of a pinhole in a narrow strip of sheet lead $\frac{1}{2}$ to 1 inch in width and 12 inches in length. If pulled across a cassette by a string attached to one end while an exposure is being made, a row of spots similar to those produced by the top will result (Fig. 63). Protecting the rest of the film with sheet lead will permit of making a number of exposures on the same film, during the making of which the speed of the strip across the cassette may be varied.

STEREOSCOPIC FILMS.

For certain regions of the body stereoscopic x-ray films possess distinct advantages. In fact it may be said without much exaggeration that, where indicated, stereoscopic films furnish as much more information than single films as single films do over no x-ray examination at all. Stereoscopic films are particularly indicated in examining regions of the body that contain a considerable quantity of radiopaque material, as the chest, vertebral column, and skull, and in regions where views at right angles to each other are difficult or impossible, as in examining the upper ends of the femora and hip joints or the shoulder. The information yielded by stereoscopic films is so valuable that a laboratory doing any considerable amount of diagnostic work should not be without the apparatus necessary for exposing and examining such films.

The value of stereoscopic films lies in the fact that when they are examined there is added to the length and breadth of the single film a third dimension, depth, of the images shown on them. This gives perspective, making the structures appear more nearly their exact shape. On stereoscopic films of the thorax, for instance, the curvature of the ribs is clearly seen, the mediastinal contents and lungs appearing suspended in the interior of the bony thoracic cage; on those of the vertebral column the bodies of the vertebræ appear anterior to the laminæ, pedicles, and articular and spinous processes, so that the smaller parts can be examined for disease or injury by looking through the images of the bodies.

Stereoscopic films are made by exposing two films, with the part of the body and the films in exactly the same position, but with a different position of the anode of the tube for each exposure.

If the part of the body is to remain immobile during the exposure of two films, then some device must be used for changing the films without disturbing the part. This is provided for by the use of cassette-changing tunnels (Fig. 64), a stereoscopic shift built into a table, or by means of stereoscopic cassette-shifting devices especially made for use in exposing large films. The cassette-holding pan of a Potter-Bucky diaphragm may also be used for the same purpose. In addition to a Potter-Bucky diaphragm the requirements of a laboratory may be met by one or two cassette-changing tunnels, of which the 12- by 12-inch size is probably the most useful, and an automatic plate changer. For large films requiring rapid exposures the cassette changer may be used; for large films permitting of a long exposure the Potter-Bucky diaphragm should be used; for smaller films of relatively thin parts not requiring the diaphragm, as the knee, shoulder, or foot, the 12- by 12-inch tunnel may be used.

In exposing stereoscopic films, the distance and the direction of the shift of the tube between the two exposures are both of considerable importance. In a measure the distance of the tube shift is controlled by the construction of the stereoscope in which the films are to be examined. These are made with a distance of 25 to 28 inches between the mirrors and the view boxes. For a 25-inch distance between the mirrors and boxes and a 25-inch anode-film distance in exposing the films, the tube shift should be 2½ inches. Two and a half inches is the distance between the pupils of the eyes, a tube shift of this distance or its equivalent being required to produce the stereoscopic effect when the films are examined.

It is best not to expose stereoscopic films at a shorter distance than 25 inches. A longer anode-film distance is permissible, but the tube shift must be increased. In determining the tube shift the controlling factors are the interpupillary distance and that from the mirrors to the view boxes of the stereoscope. The former is

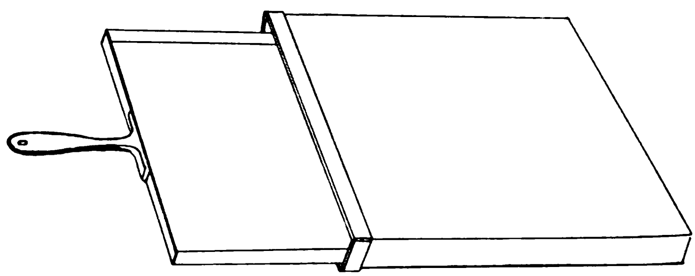

FIG. 64.—A 12- by 12-inch cassette changing tunnel.

2½ inches, the latter 25 inches; the former is 10 per cent of the latter. If this ratio be maintained, making the tube shift 10 per cent of the anode-film distance, then the ratio between the interpupillary and mirror-view box distances necessary when the films are examined will also be maintained. This establishes the rule for determining the tube shift for making stereoscopic films at a greater anode-film distance than 25 inches: The tube shift should be 10 per cent of the anode-film distance—a 3.5-inch shift for 35 inches, a 4-inch shift for 40 inches, a 6-inch shift for 60 inches, etc. In examining films made by observing this rule, the distance between the mirrors and view boxes of the stereoscope should be 25 inches.

The direction of the tube shift in exposing stereoscopic films is controlled by the direction of the predominating lines in the part being examined. The tube shift should be as nearly as possible at right angles to these lines. In the thorax the predominating lines are the borders of the ribs, therefore the tube shift should be along

the vertebral column. In the vertebræ the predominating lines are formed by the margins of the bodies, the laminæ, the pedicles, and the transverse processes, therefore the tube shift should be parallel with the long axis of the column. In making films of long bones the shift should be across the bones; for those of the skull, it may be in either direction, depending on whether structures in the base or vault or in the anterior or posterior regions are being investigated. The direction of tube shift for stereoscopic films will be given in the consideration of the roentgenography of each region.

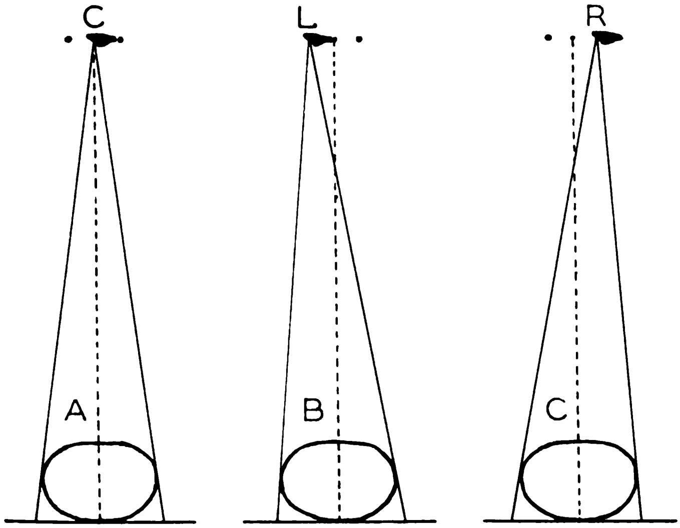

FIG. 65.—The tube shift in stereoscopic roentgenography. A, the tube centered over the part to be exposed; B, the shift of half the distance in one direction for the first exposure; C, the shift of the full distance in the opposite direction for the second exposure.

In exposing stereoscopic films the part of the body is arranged on or in front of the plate-changing device in the same manner as if a single film were to be made, allowing slightly larger margins of the film to project beyond the part in the direction of the tube shift. Center the tube over the part as if a plane film were to be exposed, previously arranging the tube to permit of the necessary shift (A, Fig. 65). For the first film, from the center position move the tube in the proper direction one-half the distance of the shift (B, Fig. 65). It is now in position for the exposure of the first film. When this has been made, for the second film the tube should be moved past the center position an equal distance, and the second film exposed (C, Fig. 65). Except to cover the same area of film when using a small cone, tilting of the tube merely complicates the process and is unnecessary.

Moore describes a method of multiple stereoscopy whereby two sets of stereoscopic films are made on three films. The first and second films are made as in the usual method. The tube is then returned to the position for the first film; from there moved in the opposite direction the required distance and the third film exposed. The first two films will give a stereoscopic pair in one direction, either transversely or longitudinally as the case may be; the first and third film will give a pair in the opposite direction. Grier recommends the making of three films of the nasal accessory sinuses so that the first and second, and the second and third will make two sets of stereoscopic exposures. Bowen and Bishop describe an ingenious device in the form of a plate or cassette changer by the use of which two or more sets of stereoscopic exposures, as of a joint in both the antero-posterior and lateral directions, may be made on one set of films for simultaneous viewing in the stereoscope. Other devices for special applications of stereoscopic roentgenography have been described.

In exposing stereoscopic films the intensifying screens should have the same speed, the exposures should be exactly the same, and the films should be carried through the different steps of the development together. They cannot be studied with any degree of satisfaction until they are dry.

Since there are many ways of doing so, only one of which is correct, placing stereoscopic films in the view boxes of the stereoscope preliminary to examination should be done with care. In viewing stereoscopic films, the eyes of the examiner, relative to the films, should be in the position of the anode of the tube; thus the images of the part of the body will be viewed from the same aspect as that with which they were made. Films of the chest made with the tube at the back will appear as if the examiner were looking into the thorax from the back; the bodies of the vertebræ will appear in front of the processes on films made in the supine position with the tube anteriorly.

To obtain the correct view, one of the films must be seen with the right eye, the other with the left. To determine which of the two films is to be viewed with the right and left eyes respectively, the films should be superimposed and held in the erect position so that the numbers on them read correctly. By looking through them at a source of illumination it will be seen that the images do not coincide. If the tube shift has been transverse, the image on one film will appear nearer the left margin of the film (B, Fig. 66). This is the film that belongs to the right eye, the other belonging to the left (A, Fig. 66). If the tube shift has been longitudinal, one of the films will have its image nearer the bottom of the film (A and B,

Fig. 67). This film should be viewed with the right eye and the other with the left.

Furthermore, in examining the films in the stereoscope, the mirrors will reverse the images, so that if they are to be seen correctly they must be placed in the view boxes reversed.

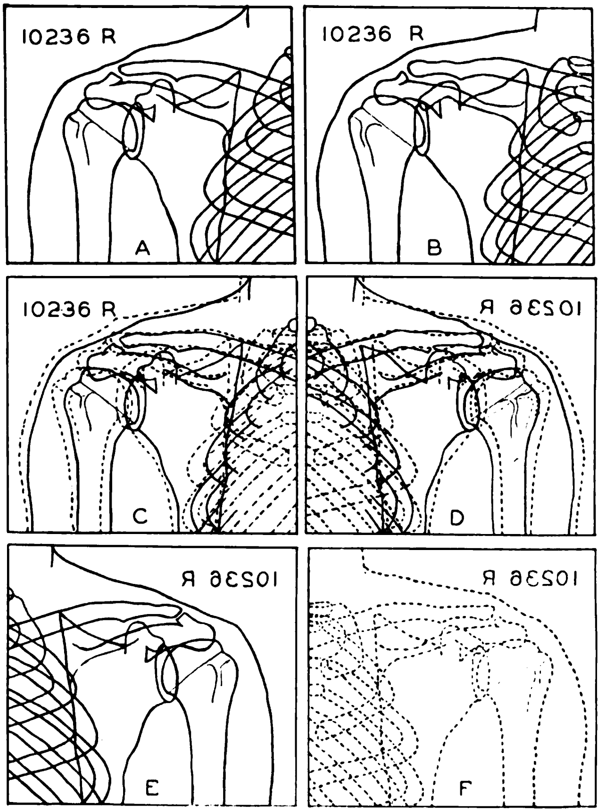

Fig. 66.—Stereoscopic roentgenograms exposed with a transverse tube shift. A, the film for the left eye; B, the film for the right eye. In placing the films in the stereoscope they are superimposed, C; then reversed on a vertical axis, D; the film with the image nearer the right margin is put in the right view box with its right margin toward the front, F; the other film is put in the left view box with its right margin toward the back of the box, E.

The directions for placing the films in the proper position in the stereoscope boxes differ for the two types of tube shift. For those made with a transverse shift, the films are held superimposed with the numbers reading correctly and viewed in one of the illuminating boxes (C, Fig. 66). Reverse the images by turning the films over on a vertical axis (D). Select the film on which the image now appears nearer the right-hand margin (F) and place it in the right-

hand view box with its right margin toward the front of the box. Then turn toward the left and place the other film in the left-hand view box (E) with its right margin toward the back of the box.

Stereoscopic films made with the shift along the long axis of the part of the body must be seen in such a way that it appears to be

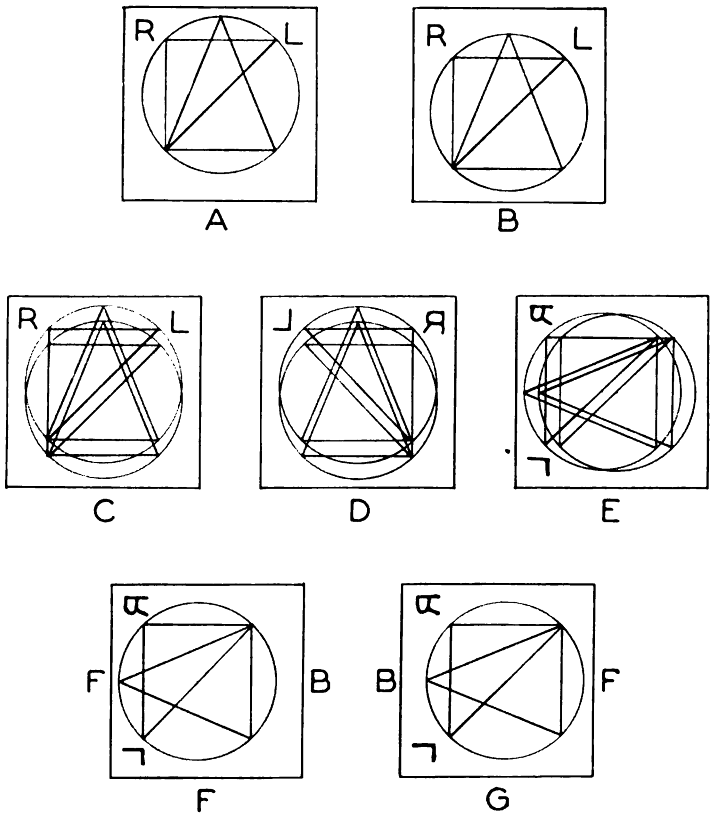

Fig. 67.—An asymmetrical figure illustrating stereoscopic films exposed with a longitudinal tube shift. The one with the image nearer the top, A, is the film for the left eye; the one with the image nearer the bottom, B, is for the right eye. In placing such films in the stereoscope they are first superimposed, C; reversed on a vertical axis, D; then turned a quarter turn with the tops of the films moving to the left, E. In this position the one with the image nearer the right margin is selected and placed in the right view box, with its right margin toward the front of the box, G; the other film is placed in the left view box with its right margin toward the back of the box, F.

lying on its left side. The films are superimposed with the numbers reading correctly (C, Fig. 67). They are then reversed by turning them on a vertical axis (D) and are also turned a quarter turn so that the tops of the films move to the left (E). In this position the film with the image nearer the right margin is selected (G) and

placed in the right-hand view box with the right margin toward the front of the box. The other film (F) is placed in the left-hand view box with its right margin toward the back of the box.

In examining the films the mirrors are slid backward and forward, tilted from side to side, and moved so that the angle between them is either increased or decreased until a single distinct image, with clear perspective, is seen. Since the stereoscopic effect increases as the study continues, the films should not be looked at, but should be minutely studied.

TERMINOLOGY.

The human body is a very complicated structure, one that is continually changing its position and the position of its many parts. Because of the changes which take place, it has been necessary to establish a particular position for the body and all of its parts and devise a terminology to designate the different aspects and surfaces. These are used for all anatomical descriptions, irrespective of the position the body or any of its parts may be in at the time the description is written. This, often spoken of as the anatomical position, is: the body erect, the upper extremities hanging at the sides, and the palms of the hands turned forward.

In this position the aspect of the body in front is spoken of as the anterior aspect or anterior surface; that behind as the posterior aspect or surface. The terms ventral (venter, belly) and dorsal (dorsum, back) are also used interchangeably with anterior and posterior. One exception to this may be noted—the supper surface of the foot is known as the dorsum or dorsal surface. When speaking of the different aspects of the upper extremity, the terms anterior and posterior are used for the arm, the term palmar or volar (vola, palm or sole) for the anterior surface of the forearm and palm of the hand, and the term dorsal for the posterior aspect of the forearm and hand. Because the radius is located under the border of the aspect of the forearm that supports the thumb, this border is often spoken of as the radial aspect or border. For the same reason the opposite border or aspect is called the ulnar.

The terms right and left, or their Latin equivalents dextra and sinistra or the adjectives dextral and sinistral, are applied to the corresponding aspects of the body. The words medial (medius, middle) or mesial (mesos, middle) and lateral (latus, side) are used to designate parts nearer to or farther removed from the middle or from the side of the body. Thus the radial aspect of the forearm would be the same as the lateral and the ulnar would be the same as the medial or mesial.

Since the position of the part of the body should always be given in describing a roentgenogram of that part, the practice has arisen of using compound words for designating the different positions. The first part of the word indicates the surface or aspect nearer the *x*-ray tube and into which the rays are directed; the second part indicates the surface or aspect in contact with the cassette and from which the rays emerge. For example, the word antero-posterior would indicate that the rays entered the anterior aspect and emerged on the posterior to strike a film in contact with the latter. Other terms such as postero-anterior, ventrodorsal, dorsoventral, dorsopalmar, dextrosinistral, radio-ulnar, etc., are self-explanatory.

Proximal and distal are terms common in anatomy that are being used more and more in general medical descriptions. The term proximal means nearer the trunk of the body or nearer the point of origin or beginning of a vessel, nerve, etc.; distal is the opposite of proximal. Thus the upper extremity of the humerus would be the proximal extremity, the upper would be the proximal phalanx; the lower or inferior end of the humerus and the lower phalanx would be the distal extremity or phalanx, as the case may be.

The terms lateral and transverse are used in designating views made transversely through a part of the body. When used in connection with an extremity or even the trunk, they indicate views made at right angles to the antero-posterior direction. Oblique would apply to views made with the rays directed obliquely. To designate the different oblique views the aspect of the body in contact with the cassette and from which the rays emerge may be used. A right anterior oblique view would be one made with the cassette in contact with the right anterior portion of the chest, the rays being directed into the left side of the body posteriorly. The other oblique views are the left anterior oblique, the left posterior oblique, and the right posterior oblique. These may also be designated as the first, second, third, and fourth oblique positions and views (U. S. Army Manual).

Unless correct anatomical usage is adhered to, considerable confusion may occur with reference to the use of the terms arm and leg. The arm is that part of the upper extremity between the elbow and shoulder; the leg that part of the lower extremity between the ankle and knee. Other major portions of these extremities are the forearm and thigh. If the entire extremity be indicated, it should be so stated. Any other usage of these terms is incorrect and should not be practiced.

THE PREPARATION OF PATIENTS.

The shadows of fecal material and gas in the colon on films of the lumbar part of the vertebral column, the pelvis, or any of the abdominal viscera, often obscure the images of other structures and make interpretation difficult. For this reason the best films will be those exposed when the large intestine is completely empty. Preliminary to many examinations, this requires some preparation of the patient especially to empty the colon of its contents. Unless contra-indicated, preparation of this kind should precede examinations of the gall bladder with or without the use of an opaque dye, any part of the urinary tract, films of the lumbar vertebræ, films of the sacrum and coccyx, and before the examination of the colon with an opaque enema. The images of the kidneys and the coccyx and distal part of the sacrum are so apt to be obscured that emptying of the colon before examinations of these structures is particularly important.

Common methods for attempting to rid the colon of fecal material and gas include enemas and laxative and cathartic medicines of various kinds. To these have recently been added the use of "pitressin," the pressor principle from the posterior lobe of the pituitary gland, to stimulate peristaltic activity of the intestines.

Cleansing enemas probably are the simplest method of emptying the large intestine of its contents. If the patient be ambulatory and in good condition, the results are usually satisfactory; if the patient be confined to bed, has been ill for some time, has been given drastic purges, or has had morphine for the control of pain, the results very often are unsatisfactory. Weakness of a patient or confinement to bed makes it difficult or impossible to discharge an enema administered for this purpose. Purgation and the administration of morphine probably cause a spasticity of the colon from which it is very difficult to dislodge the fecal material and gas.

Enemas should be of large size, from 1½ to 2 quarts; they should be injected slowly and under a low pressure with the container not more than 3 feet above the level of the tip. The patient should be in the supine position and all of the solution should be injected before any of it is expelled. Enemas of lukewarm tap water, of water to which a teaspoonful of soda to the quart has been added, and of soapsuds have been suggested. There is some objection to the use of soapsuds because considerable air is held in suspension and is injected with the solution. Enemas of water to which soda has been added are probably as satisfactory as any. Since gas rather quickly reforms in the colon, examinations should be made shortly after the enema has been completely discharged.

Drugs that have been recommended for this purpose include compound licorice powder in 1 to 2 tablespoonful doses given in milk, castor oil in doses of from 1 to 2 ounces, and large doses of the saline laxatives. Both castor oil and saline preparations have been objected to on the ground that they cause gas in the colon, one writer objecting to castor oil for this reason and using the salines, another using the salines in preference to the castor oil for the same reason. Magnesium citrate in full doses is probably as good a preparation as any. As with enemas, the examination should be made soon after the laxative has acted.

In 1936 Collins and Root introduced the use of pitressin as a preliminary to cholecystography for the purpose of stimulating the peristaltic activity of the intestinal tract and ridding the colon of gas and fecal material. In 1937 Kenning and Lofstrom recommended its use as a routine in preparation for cholecystography, for any examination of the urinary tract, including retrograde or intravenous urography, and for the examination of the lumbar spine and pelvis. In 1939 Kirklin and Seedorf published the results of a careful study of the reactions following the use of this preparation in cholecystography.

The patient may be given a cleansing enema the night before the contemplated *x*-ray examination. A second enema is given on the morning of the examination. From thirty minutes to an hour before the examination the patient is given an ampoule of pitressin (20 pressor units) into the deltoid muscle. In about three-fourths of the patients this will result in a bowel movement and the passage of gas from the rectum within thirty to forty-five minutes. The *x*-ray examinations are made shortly after the drug has acted, for the gas returns in two or three hours.

The use of pitressin is followed by some mild reactions. These are listed by Kirklin and Seedorf in the order of their frequency of occurrence as intestinal cramps, pallor, belching, faintness, dizziness, nausea, headache, vomiting, visual disturbances, tinnitis, and in 37 per cent of the female patients pelvic pain resembling menstrual or uterine cramps. In all instances the reactions were transitory, and no case of severe or fatal reaction has been observed.

Cardiac decompensation associated with marked hypertension, coronary sclerosis and thrombosis, hypertension, and acute complete intestinal obstruction are listed as contraindications to the use of pitressin.

Pitressin has been found a very useful adjunct in the preparation of patients for *x*-ray examinations where intestinal gas and feces interfere with satisfactory roentgenograms, and where preparation without its use has been unsuccessful. It is particularly indicated

in patients that are confined to bed, in patients that have had drastic purgation within a few days, and in those that have been given opiates within the past forty-eight hours for the relief of pain from biliary or renal colic.

CLOTHING.

Proper attention should be given the clothing worn by a patient during a roentgenographic examination. As far as possible all clothing should be removed from the part being examined. Cotton underwear without buttons or metallic fasteners is unobjectionable. Garments either partly or wholly of silk should always be removed, for such materials often are impregnated or "loaded" with metallic substances that are sufficiently radiopaque to cause shadows on films. I have seen a narrow silk ribbon in the top of cotton underwear cast a shadow equal in density to that of the ribs, and a full silk garment seriously impairs detail on films. A cotton kimono fastened with strings that tie around the body and constructed so that it may be adjusted to accommodate any body circumference is a most satisfactory garment to wear during roentgenographic examinations. Several such garments should be kept on hand for use in an *x*-ray laboratory. Male patients, when films are made by male examiners, may, of course, be stripped and examined nude.

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CHAPTER XIII.

THE UPPER EXTREMITY.

THE HAND.

THE bony framework of the hand is composed of five metacarpal bones and fourteen phalanges. These are classified as long bones, each having a flattened or cylindrical shaft of compact bone and two cancellous extremities. The spade-shaped ungual expansions of the distal phalanges support the nails. The metacarpophalangeal and interphalangeal joints are hinge joints with a considerable range of motion. The carpometacarpal joint of the thumb is freely movable and there is some movement in that of the fifth digit. There is very little motion at the other carpometacarpal articulations.

Any part of any bone of the hand may be injured and require examination. The most common probably are crushing injuries of the ungual expansion of the distal phalanges, transverse and oblique fractures of the phalanges near the middle of their shafts, transverse or oblique fractures of the metacarpal bones, and fractures of the metacarpal bones near their heads with angulation of the distal fragments toward the palm and impaction of fragments on their volar aspects.

By placing the palm of the hand on a cassette with the fingers slightly separated, a direct dorsopalmar view of any part of the hand, except the thumb, may be made (Fig. 68).[1] In this position the bones of the thumb will be shown in a mediolateral oblique view. Transverse or lateral views at right angles to the dorsopalmar may be obtained of the bones of the fingers, except the upper halves of the proximal phalanges. In making such views of the fingers, the ulnar aspect of the little finger or the radial aspect of the index finger may be pressed against the film holder with the other fingers flexed into the palm of the hand. For views of the middle and ring fingers the holder may be elevated, the ulnar aspect of the finger placed against it, and the other digits either flexed into the palm or extended dorsally to the one being examined (Fig. 69).

[1] The photographs of positions shown in this and following chapters do not include in some particulars all the details of the arrangement of the part and the x-ray tube used in practice. Care was taken to have the part of the body in the actual position and the x-ray tube correctly placed. To include the tube in the photograph the anode-film distance may be considerably shorter than that recommended in the text. Usually the devices for immobilization have been omitted. To make the reproductions of the films of uniform size, it was necessary to make all exposures lengthwise of the films and to make a single exposure on each film. In many instances this differs from the practice recommended in the text. Except in a few instances all structures shown on the films are normal.

To obtain a dorsopalmar view of the thumb it is necessary to flex the thumb at the carpometacarpal joint to a right angle with the palmar surface of the hand, elevate the cassette from the table or place it along the edge of the table, and put the palmar surface of the thumb against the cassette. In this view the proximal end of the metacarpal bone will not be included. A somewhat distorted image of the bones of the entire thumb in the dorsopalmar direction may be obtained by flexing the thumb at a right angle with the palm, placing the ulnar margin of the hand on the cassette, and resting the tip of the thumb on some support. A small pasteboard box or a large cork will serve for this purpose. A ventrodorsal view of the thumb

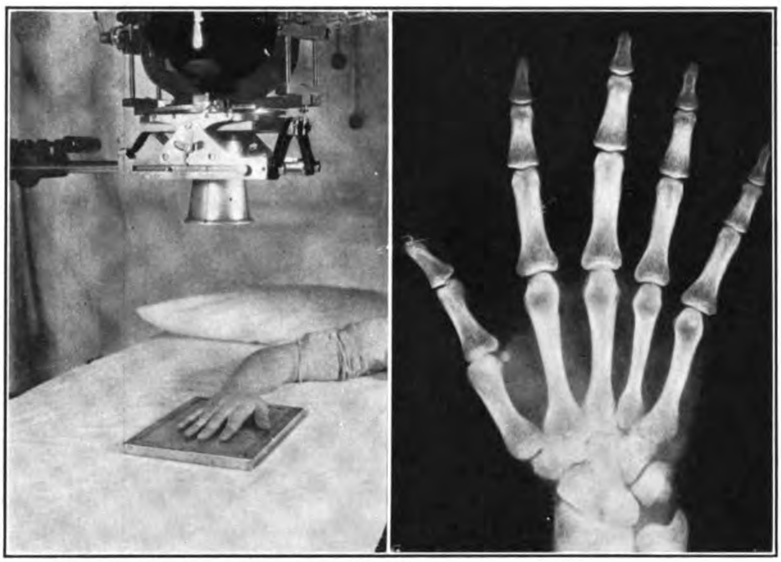

FIG. 68.—Dorsopalmar exposure of the hand.

may be made by placing the dorsal aspect against the cassette with the palmar surface up. A directly transverse view of the thumb may be made by placing the radial aspect against the cassette, slightly elevating the palm, and bending the fingers to permit the thumb to maintain this position (Fig. 69).

Directly transverse views of the metacarpal bones and the upper ends of the proximal phalanges of the four fingers are of little value. When the hand is held in the thumb-up position and a film exposed, the images of these bones are so superimposed that the identification of any particular one is difficult. For the second view of the metacarpal region an oblique view, according to the method described by Kress and Payne, may be taken. This is made by placing the

ulnar border of the hand against the cassette with the dorsal surface of the metacarpal region forming an angle of 45 degrees with its surface (Fig. 70). The little finger may be slightly extended and the other digits flexed so that their tips touch the cassette. If the fingers be extended and the hand and fingers held at an angle of 45

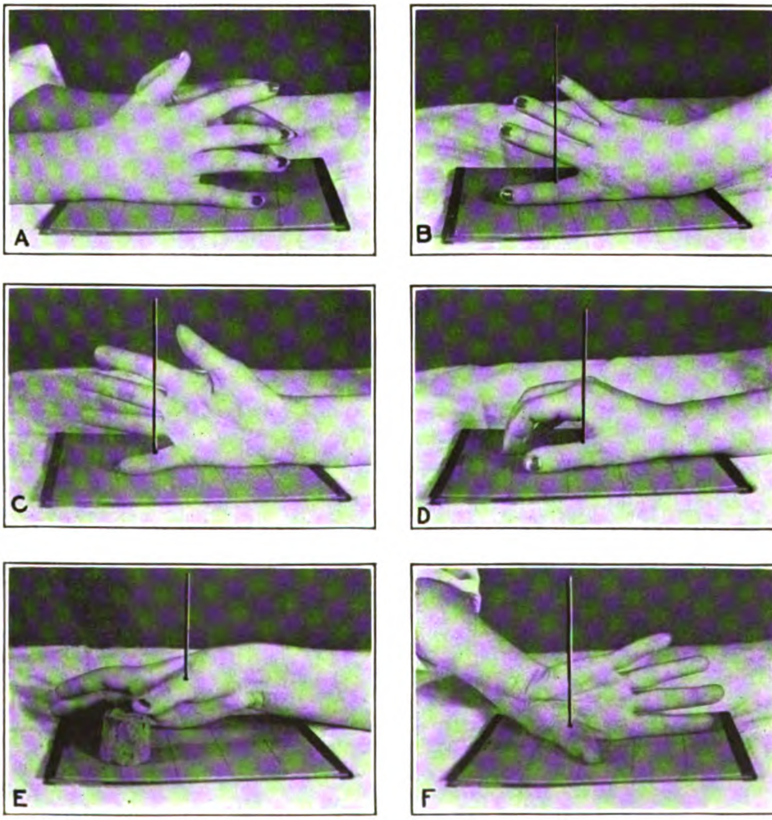

Fig. 69.—A, position for an oblique exposure of the metacarpal bones and phalanges. The hand is placed in an oblique position and supported by the fingers and thumb of the opposite hand. B, position for a transverse exposure of the index finger. C, position for a transverse exposure of the little finger. In B and C, the other fingers may be flexed instead of extended. D, position for a lateral exposure of the thumb. The thumb will not be in the proper position unless there is some extension of the wrist and flexion of the fingers. E, position for a dorso-palmar exposure of the thumb, with the thumb at right angles to the hand and tip supported by a large cork. F, position for a ventro-dorsal exposure of the thumb with the forearm in a position of extreme pronation and the dorsal aspect of the thumb against the film.

to 60 degrees to the film surface with the fingers steadied by those of the opposite hand, a satisfactory oblique view of the hand may be obtained. Even in these views the images of the proximal ends and parts of the shafts of the metacarpal bones will be partially superimposed.

The size of film required for the proper examination of the hand depends on the definiteness with which the injury or disease can be located. Usually pain or swelling will locate the trouble so that only a small film area is necessary. A $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film divided transversely often suffices. For a complete survey of all the bones of the hand, requiring a dorsopalmar and an oblique view, a larger film area is necessary—at least the 10- by 12-inch size divided transversely, or two smaller films.

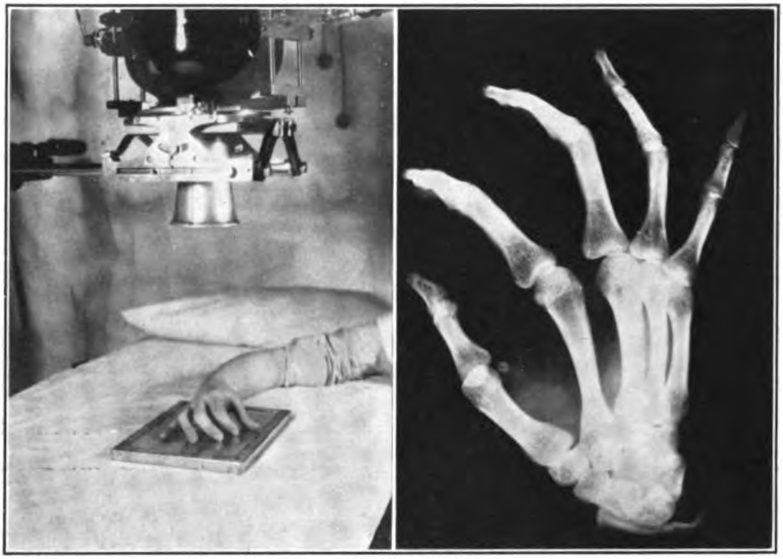

FIG. 70.—Oblique exposure of the hand particularly to show the metacarpal bones in a view differing from the dorso-palmar.

If only a part of one digit needs to be examined, such as a distal phalanx or an interphalangeal joint, this may be done very satisfactorily by using one or more dental films. In many instances dorsopalmar and transverse exposures can be made much easier with such material than with larger films. The exposure factors are the same as for the anterior teeth, except that the time should be reduced one-third.

THE WRIST.

In the wrist are included the eight carpal bones and the distal ends of the bones of the forearm. The carpal bones are arranged in two transverse rows. Seen either from above or below, the bones form a curve anteriorly which is converted into a tunnel for the flexor tendons by the transverse carpal ligament. The distal end of the radius is expanded and forms the wrist joint with the proximal row of carpal bones. The distal end of the ulna is slender, and is

separated from the carpal bones by a thick fibrocartilage. The styloid process of the ulna can be palpated on the medial aspect

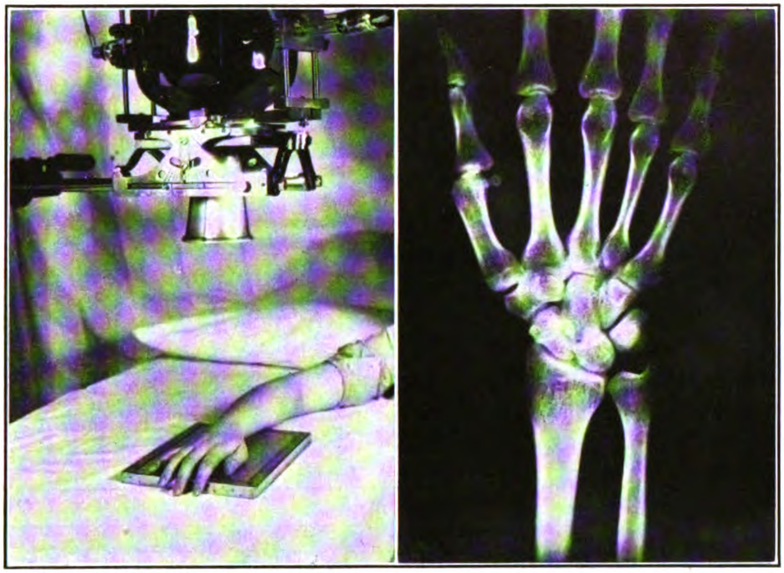

Fig. 71.—Dorsopalmar or posteroanterior exposure of the wrist.

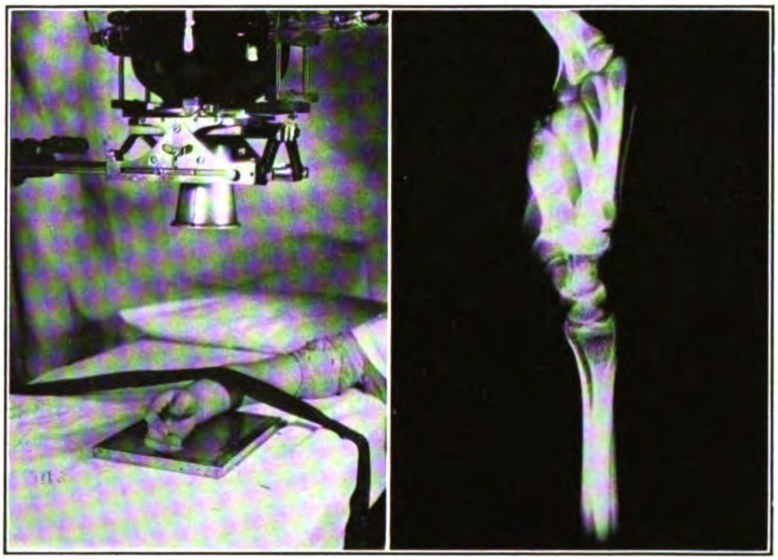

Fig. 72.—Radio-ulnar or lateral exposure of the wrist.

and that of the radius felt on the lateral aspect of the wrist joint. The joint line forms a proximal curve connecting these two points.

The carpal bones can be felt by pressing over the upper limits of the thenar and hypothenar eminences. Movements in all directions are permitted in the wrist, about one-half of flexion and extension taking place in the radiocarpal and the other half in the intercarpal joints.

Colles' fracture in adults, complicated in about one-half the cases by a fracture of the styloid process of the ulna, is a very common injury. In children fractures of both bones of the forearm in their lower 2 inches and separation of the lower epiphysis of the radius,

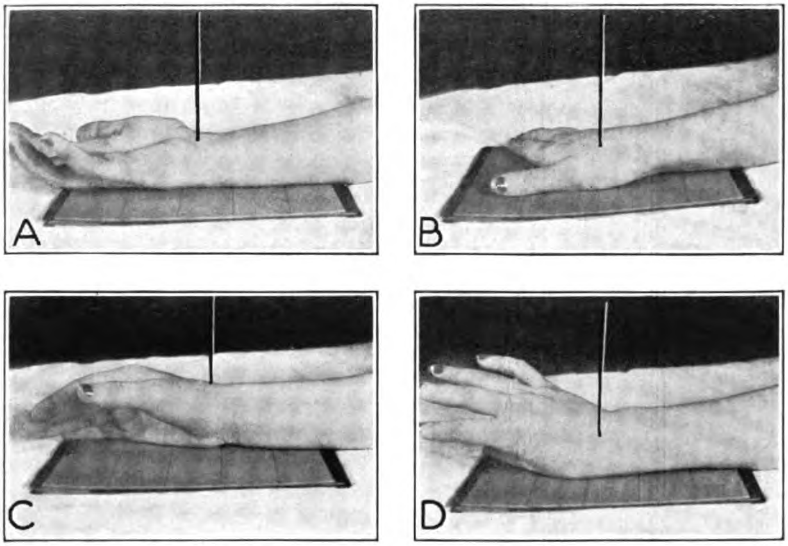

FIG. 73.—A, position for a ventro-dorsal film of the wrist. The intercarpal articular spaces are best shown on a film exposed in this position. The rays are centered just below the lower crease on the ventral aspect of the wrist. B, position for an exposure of the wrist through the carpal region with an ulnar deviation of the hand. The navicular (scaphoid) is well shown on this film. C, position for an oblique radio-ulnar exposure through the wrist. This position is best for the navicular bone (scaphoid) and the carpo-metacarpal joint of the thumb. D, position for an oblique ulno-radial exposure of the wrist. The two oblique views are important in examining for sprain fractures.

resulting from the same kind of violence that causes Colles' fracture in adults, are less frequent. Injuries to the carpal bones are rare. Most common are fractures of the navicular (scaphoid) and a forward dislocation of the lunate (semilunar).

Roentgenographic examination of the wrist should present no difficulties. Dorsoventral or postero-anterior (Fig. 71) and lateral or radio-ulnar views are required (Fig. 72). Since the displacement in fractures and in the dislocation of the lunate are in the antero-posterior direction, the radio-ulnar or lateral view is the more

important and should never be omitted. For both views the tube is centered directly over the radiocarpal joint, for which the transverse grooves in the skin on the front and back of the wrist or either of the styloid processes are good guides. A view made with the back of the wrist against the plate will show the carpal bones and the spaces between them better than the dorsoventral view. For the detection of sprain fractures, small fragments broken off the surfaces of the bones, Archer and Rawles recommend oblique views of the bones of the wrist in addition to the dorsopalmar and lateral exposures (Fig. 73). Only small film areas, either the 6½- by 8½-inch or the 8- by 10-inch size divided transversely, or four exposures on a larger film, are required.

Special examinations of the bones of the wrist may sometimes be necessary for fractures of the navicular. The dorsopalmar view may be taken with the hand deviated to the ulnar side, or a dorsopalmar view may be taken with the hand slightly flexed and the palm elevated. However, perhaps the best exposure of the navicular (scaphoid) is the one made in a semioblique view from radial to ulnar with the radial aspect of the hand slightly elevated, and with the thumb extended and parallel with the film surface (Fig. 73).

THE FOREARM.

The radius and the ulna are the two bones of the forearm, the radius being the stronger at the distal end and the ulna at the proximal end. In the anatomical position (complete supination) these bones lie almost in the same antero-posterior plane, the upper end of the radius being but slightly anterior to that of the ulna. The interosseous space between the two bones is wider in the middle of the forearm when in a position of complete supination. In the movement from complete supination (palm forward or upward) to that of complete pronation (palm backward or downward) the radius rotates around the stationary ulna through an arc of 140 to 160 degrees. In the prone position the radius crosses the ulna, the crossing taking place in the upper parts of the bones so that the lower portions are again nearly parallel. The dorsal border of the ulna is subcutaneous throughout its extent. The upper part of the shaft of the radius is deeply placed and, except for the head and neck, cannot be palpated.

Fractures of the bones of the forearm are not uncommon injuries. Both bones are fractured more often than either one alone; fractures of the radius are more common than fractures of the ulna. The displacement and the deformity that occurs in these fractures depends on the kind and direction of the violence, the portion of the

bone or bones involved, and the action of the muscles. Careful roentgenographic examination is required to determine accurately the position of the fragments. Views in the antero-posterior and lateral directions, accurately made and at right angles to each other, are required.

The average length of the bones of the forearm is from 10 to 12 inches. For views of both bones throughout their extent either a 10- by 12- or 11- by 14-inch film is necessary. If divided longitudinally and each half exposed separately, the two required views may be shown on the same film. For less than the entire extent of the bones a smaller film may be used.

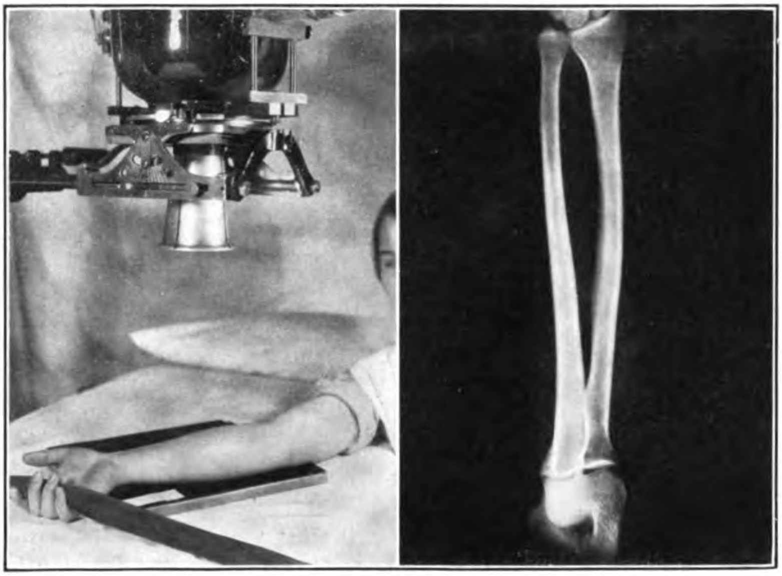

Fig. 74.—Antero-posterior or ventro-dorsal exposure of the forearm.

When possible the antero-posterior view should be made with the forearm completely supinated and with the dorsal surface in contact with the cassette. The supination should be complete, with the elbow extended and the palm of the hand facing directly upward (Fig. 74). To accomplish this the entire humerus and arm must be in a plane perpendicular to the table top. For the lateral or radio-ulnar view the position of the forearm mentioned above is maintained and the entire extremity is rotated through the required 90 degrees (Fig. 75). This movement takes place at the shoulder, but greater flexion of the elbow is permissible. The forearm remains in a position of supination with the thumb directed upward. Instead of being in a plane perpendicular to the table top, the arm must then

either be on the table or in a plane parallel with it. To obtain this position, it may be necessary to place an adult patient on a low stool or a child on a high stool at the side of the x-ray table.

When a patient has sustained a severe injury to the forearm, because of pain it may be difficult to get the positions described in the preceding paragraph. Usually the forearm is held in a sling across the front of the body in a position about halfway between supination and pronation, with the thumb uppermost, or it may be in a splint or cast in this position. With the elbow flexed and the shoulder dropped until the arm is on the table, gently place the forearm on the film holder and a dorsoventral view can be secured. The

FIG. 75.—Radio-ulnar or lateral exposure of the forearm.

transverse or lateral view can be secured in one of two ways: (1) by elevating the patient either on a stool or in a semistanding position, the ulnar side of the forearm can be brought in contact with the film holder, or (2) the film holder can be placed on its side in a vertical position and the rays directed perpendicularly to it (Fig. 76).

If there has been a fracture of one or both bones of the forearm and the examination is made particularly for the growth of callus, the directly transverse view may superimpose the shadows of the two bones and obscure the fractures. Then it is advisable to make four exposures, an oblique radio-ulnar and an oblique ulnoradial view as well as the dorsoventral and lateral exposures. The liberal

use of sand bags and some angulation of the tube may be necessary for making these exposures.

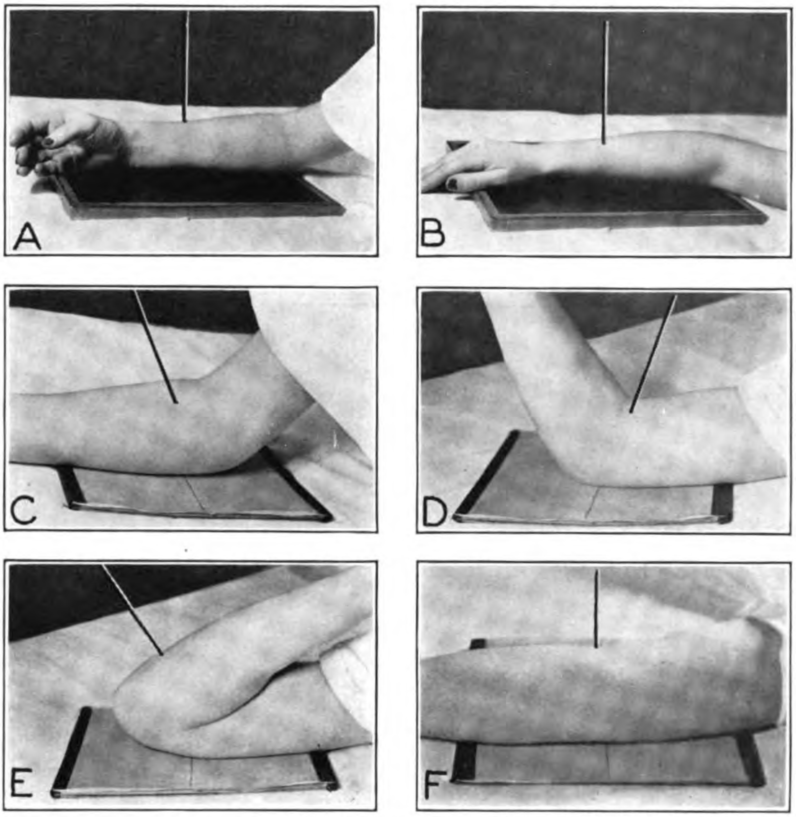

FIG. 76.—A, position for a radio-ulnar exposure of the forearm with the forearm incased in splints. Often the splints extend above the elbow, which would cause more flexion than is shown in the figure. B, position for a dorso-ventral exposure of the forearm when the extremity is incased in a splint. Note particularly that the arm is resting on the table. C and D, position for antero-posterior exposures through the region of the elbow when it is impossible completely to extend the forearm. In C, the proximal ends of the radius and ulna below the joints are taken; in D, the distal end of the humerus above the joint is taken. E, position for a view through the flexed elbow. The arm and forearm are in the same vertical plane perpendicular to the film. This position is used when the extremity is placed in the Jones position following reduction of a supracondylar fracture of the humerus. F, position for a special view of the head of the radius. The elbow is completely extended and the extremity is in a position of extreme supination and lateral rotation.

THE ELBOW.

The elbow is composed of the proximal ends of the radius and ulna, the distal end of the humerus, and the joints between them. The elbow joint is composed of three parts—that between the humerus and ulna, that between the humerus and radius, and the

proximal radio-ulnar articulation. At the upper end of the ulna the semilunar notch is formed below by the strong shelf-like coronoid process and behind and above by the equally strong olecranon. The semilunar notch fits around the trochlear articular surface of the humerus. The adaptation of the bones is such that the joint is a pure hinge joint, the motions of flexion and extension only being permitted.

In addition to the radial tuberosity, the upper end of the radius is made up of the constricted neck supporting the flattened head. The proximal surface of the head is slightly concave for articulation with the capitulum of the humerus. The margin of the head is received into the radial notch on the lateral aspect of the coronoid process of the ulna, forming the proximal radio-ulnar joint. The joint between the radius and humerus is also of the hinge variety; that between the radius and ulna is classed as a pivot joint. The ligaments holding the radius and ulna together are stronger than those holding the radius to the humerus, thus accounting for the frequency of the dislocation together of both bones of the forearm.

The distal extremity of the humerus is expanded from side to side and flattened from before backward. It is also slightly curved in an anterior direction. At its lowermost part it supports the capitular and trochlear surfaces for articulation with the radius and ulna. Above these two surfaces on the medial and lateral aspects are the bony prominences called the medial and lateral epicondyles, the medial of which is more distally placed and more prominent than the lateral.

The medial and lateral epicondyles, the olecranon process of the ulna, and part of the head and neck of the radius are subcutaneous and easily palpable. On the dorsal aspect of the elbow a distinct groove separates the lateral epicondyle from the head of the radius. This groove is formed by the radiohumeral articulation which is at the same level as the inferior part of the joint between the humerus and ulna.

Any part of the bones about the elbow may be injured and any of the joints may be dislocated, but by far the most common injuries are fractures of the lower end of the humerus, of which there are at least six varieties, fractures of the head of the radius, and backward dislocations of both bones at the elbow joint. Injuries in this region vary in severity from cracks in the head of the radius or in the lower end of the humerus to complete fractures above the condyles with considerable displacement and marked deformity. A patient with an injury in the region of the elbow should not be treated for a sprain unless a carefully made *x*-ray examination has shown the absence of bone injury.

Roentgenograms of the elbow should be made in both the antero-posterior and lateral directions. The ideal antero-posterior view is one that is made with the forearm in the supine position, the elbow completely extended, and the dorsal aspects of both the forearm

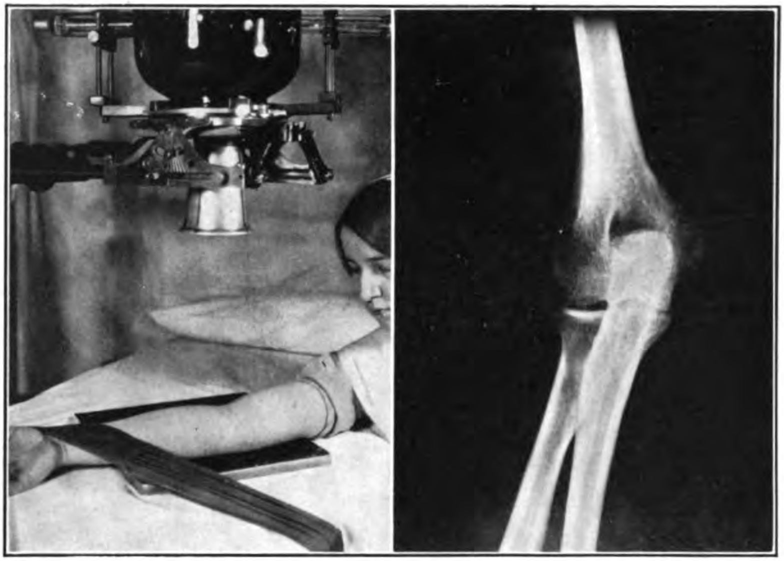

FIG. 77.—Antero-posterior or ventrodorsal exposure of the elbow.

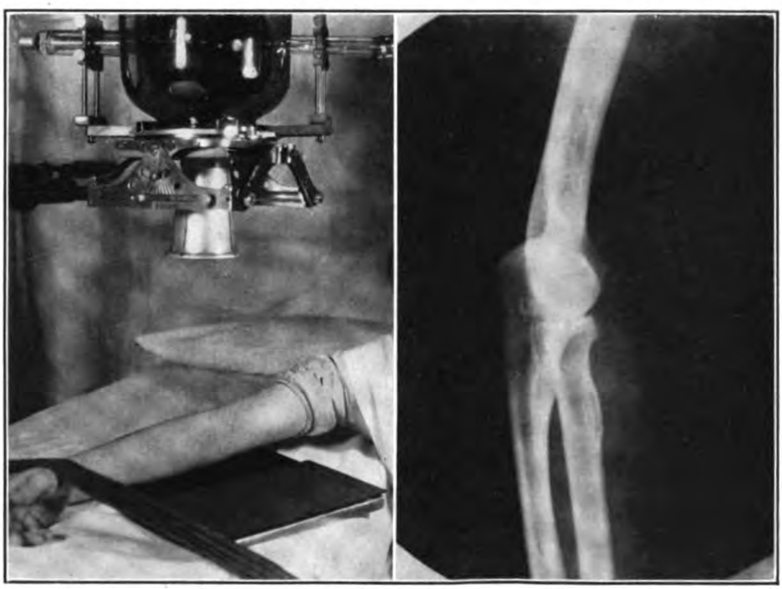

FIG. 78.—Lateral exposure of the elbow. The arm must be as near the table as possible. The elbow may be flexed.

and arm lying on the cassette (Fig. 77). The lateral or radio-ulnar view may be made through the flexed elbow with the forearm supinated, but with the thumb directed upward and the arm in contact with the cassette (Fig. 78). If the arm be not in this position and the rays are directed perpendicularly to the cassette, the view will be oblique and not as valuable as a true lateral view. Also, if the thumb be not directed upward, the hand being allowed to fall to a prone position, the view of the upper end of the radius will not be at right angles to the other view.

In practice, especially when dealing with severe injuries, the lateral view is easier to secure than the antero-posterior. By moving the extremity and supinating the forearm very slowly, the elbow usually can be arranged in the desired position. It often is impossible to completely extend the forearm. It is then necessary to use a small film and make two views, one of the bones below and the other of the bones above the joint. In obtaining these, the position of the cassette and the direction of the rays often must be accommodated to the position of the extremity. A well-planned use of sand bags and pillows and tilting of the tube will aid materially in obtaining the correct views (Fig. 76).

Injuries of the distal extremity of the humerus often are immobilized in a position of complete flexion. In this position roentgenograms are required to ascertain the position of the fragments of the injured bone. These can be secured by the usual lateral view through the flexed joint and by exposing the second film from below upward and backward with the bones of the forearm and the humerus in the same vertical plane perpendicular to the surface of the cassette. Although there will be superimposition of the shadows of the bones of the forearm and the humerus on the second film, the position of the distal fragment of the humerus can be determined. (Fig. 76).

Views of the elbow may be made on small films. The 8- by 10-inch size divided longitudinally is large enough to show the elbow and the adjacent bones. For the antero-posterior view the tube should be centered just below a line connecting the two epicondyles; for the lateral view it should be centered just in front of the lateral epicondyle.

THE HUMERUS.

The humerus is the bone of the arm. Next to the femur it is the longest bone of the body, varying in length in adults from 12 to 14 inches or more. The expanded lower end enters into the formation of the elbow joint and has been considered. The shaft is prismatic below and cylindrical above. The upper extremity enters into the

formation of the shoulder joint and will be considered with that region. While injuries of the upper and lower ends of the humerus are common, fracture through the shaft must be classed with the more uncommon bone injuries.

In roentgenography of the shaft of the humerus the accuracy of location of the injury should determine the size of the film to be used. In obtaining the two views at right angles to each other, it must be remembered that the humerus may be rotated at the shoulder joint over 90 degrees, and care must be exercised to retain the same position of the bone for the two films. Usually such injuries

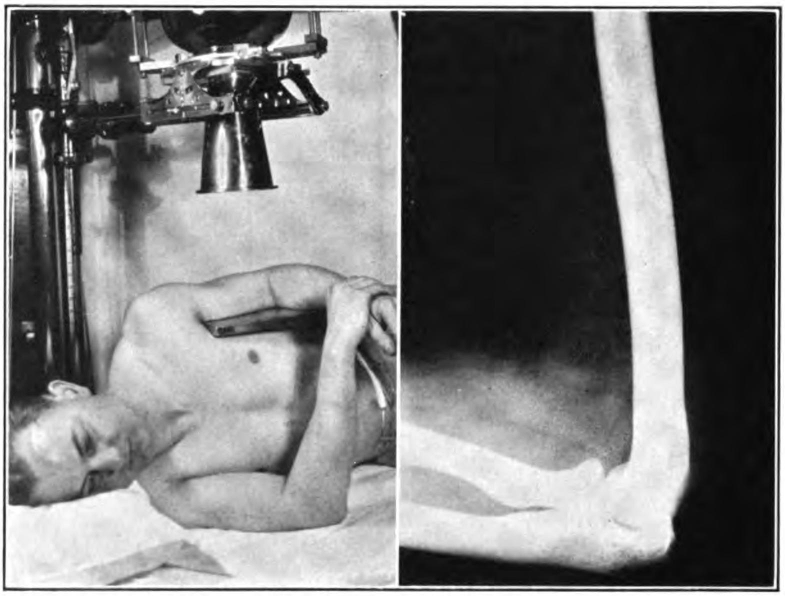

FIG. 79.—Lateral exposure of the distal part of the arm.

are so painful that little movement of the arm is permitted. A good practice is to make one view of the humerus with the patient recumbent, then, without moving the arm, rotate the patient to the lateral position with the injured side up (Fig. 79). In this position the cassette may be slipped between the arm and lateral aspect of the thorax for the second view. This may decrease the anode-film distance for the second film so that the exposure factors must be changed accordingly, usually by shortening the exposure time. In the lateral position the upper 4 or 5 inches of the humerus will be above the axillary folds, making it impossible to include them on this film.

THE SHOULDER.

The shoulder joint is formed by the articulation of the upper extremity of the humerus with the glenoid cavity of the scapula. The upper end of the humerus is formed by the hemispherical head and the greater and lesser tuberosities which are separated by the intertubercular (bicipital) groove. The lateral margin of the head at its place of union with the tuberosities is known as the anatomical neck; because of the frequency of injury at that point, the slight constriction where the tuberosities join the shaft is known as the surgical neck.

The glenoid cavity of the scapula is described as pyriform in shape and slightly broader at its upper than at its lower part. In general direction it faces lateralward with a slight inclination upward and forward. It is considerably smaller than the head of the humerus. Overhanging the glenoid fossa above and behind is the acromion process of the scapula: mesially and anteriorly it is overhung by the coracoid process with the coracoacromial ligament connecting the two processes.

The shoulder joint is a ball-and-socket joint, permitting of movements in all directions. Rotation through an arc of over 90 degrees is an important movement.

Since the medial epicondyle always points in the direction of the head of the humerus, if the bone be intact, the degree of rotation and position of the head can be ascertained by determining the direction of the medial epicondyle. Thus with the upper extremity in the anatomical position, both the medial epicondyle and head of the bone are directed medially; but with the elbow flexed and the forearm held across the chest in a sling, the head of the bone extends almost directly backward.

Dislocations of the shoulder are said to be more common than those of any other joint. While this probably is true, the dislocation is recognized and reduced by the attending physician, the patient being sent for examination to detect bone injury, making dislocations rather rare findings in a roentgenologic practice.

Fractures of the upper end of the humerus are of several kinds. They include fractures of the surgical neck, fractures of the anatomical neck, the explosive fracture of Kinney and Elliot, fractures of the tuberosities, and epiphyseal separations. Displacement in different directions with impaction and deformity are common. Many will escape detection unless *x*-ray examinations are made of all injuries to the shoulder.

The chief problem in roentgenography of the shoulder is to show

the humerus in different views in such a way that there can be no doubt as to the kind of injury, the direction and amount of displacement, and the deformity that is present. The most informative single view of the shoulder is one that is taken with the upper extremity in the anatomical position. With the patient in the supine position, the extremity lying at the side and rotated laterally as far as possible, and with the palm of the hand directed upward, the upper end of the humerus will be in the anatomical position (Fig. 80). In this position the head will project mesially and be registered in profile on the film. The lesser tuberosity will extend anteriorly and the greater tuberosity laterally, with the intertubercular groove between them.

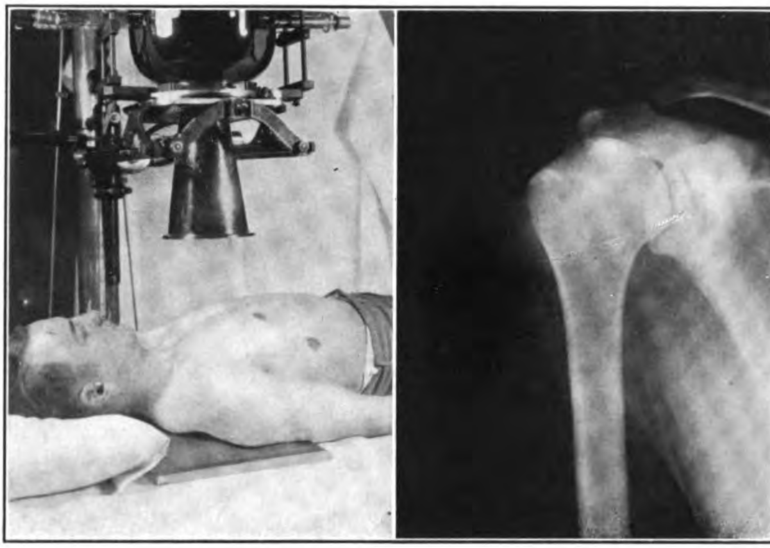

Fig. 80.—Antero-posterior exposure of the shoulder. The extremity is rotated laterally as far as possible with the palm of the hand directed upward.

The position of the central rays from the tube is of importance. This should be an inch or so medial to the tip of the coracoid process and about the same distance above. The tip of the coracoid can be palpated through the deltoid muscle in the fossa beneath the clavicle and about $1\frac{1}{2}$ inches from its acromial end. This position of the tube will tend to displace the head of the humerus from under the acromion process.

Views of the upper end of the humerus at right angles to each other are just as important as similar views of any other bone and are probably more informative than stereoscopic films. Considerable difficulty often will be experienced in securing them, and in some

instances all attempts will fail. If the humerus can be moved through an arc of 90 degrees without too much pain to the patient, the two views can be secured. The antero-posterior view may be made as described above with the extremity rotated laterally and the medial epicondyle projecting directly medially. Then if the forearm be pronated and the arm medially rotated until the medial epicondyle projects directly backward, a second view may be exposed which will be a lateral view through the upper extremity of the humerus.

An ambulatory patient with an injured shoulder usually comes with the elbow flexed and the forearm held in a sling across the chest. The patient may be placed in the supine position on the table, the elbow brought forward and supported on a pillow so that the forearm is parallel with the table. If a film be exposed with the extremity in this position, a lateral view of the upper end of the humerus will be secured (Fig. 81). Then if the humerus can be rotated laterally through an arc of 90 degrees, the arm will be in the anatomical position and the antero-posterior view may be exposed (Fig. 82).

By abducting the upper extremity to a right angle with the trunk, placing the cassette on the axillary aspect of the arm, and directing the rays from above downward, the second view of the upper end of the humerus may be taken. Tilting the tube at a slight angle laterally will displace more of the shoulder on to the film and will not cause enough distortion to impair the result. Or the position of the tube and cassette may be reversed as suggested by Lawrence by placing the cassette on top of the shoulder and directing the rays from below upward through the axilla.

If it be not possible to move the shoulder, the lateral view may be taken with the forearm across the chest as already described, and the antero-posterior view through the upper end of the humerus taken by the second method described by Lawrence. This consists of having the patient either sit or stand, without changing the position of the extremity, with the injured shoulder, slightly drooping, pressed against a cassette-holding device. The opposite extremity is held above the head. The tube is turned horizontally and the rays directed into the opposite axilla (Fig. 83). The patient is instructed to take a full inspiration and hold the breath while the exposure is made. In this manner a view of the upper end of the humerus is taken with the rays passing through the upper part of the thorax. The bone will be shown clearly enough to depict any displacement or deformity that may be present.

The shoulder joint is not in a direct antero-posterior vertical plane. Instead, it is obliquely directed with its posterior or dorsal aspect

farther lateral than its anterior or ventral margin. To obtain true profile views, which are important in studying the joint for evidences of infection, it is necessary to elevate the opposite shoulder

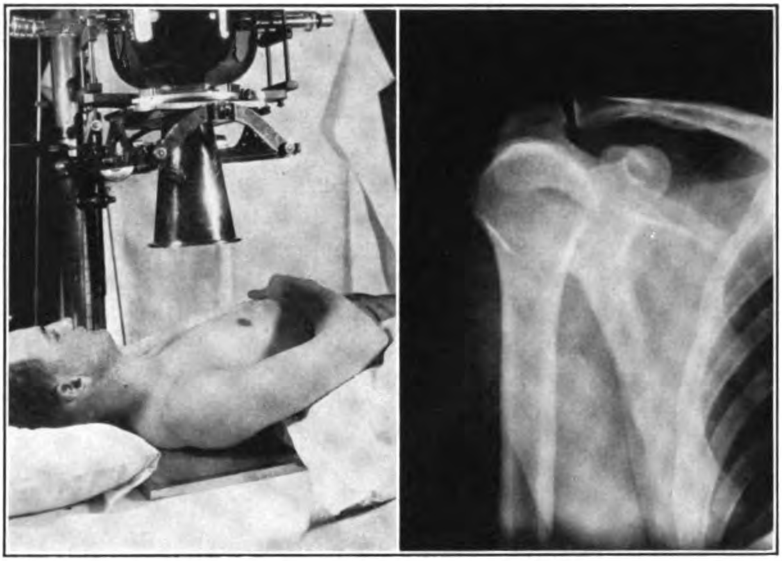

FIG. 81.—Antero-posterior exposure of the shoulder with the forearm flexed across the trunk, giving a lateral view of the proximal extremity of the humerus.

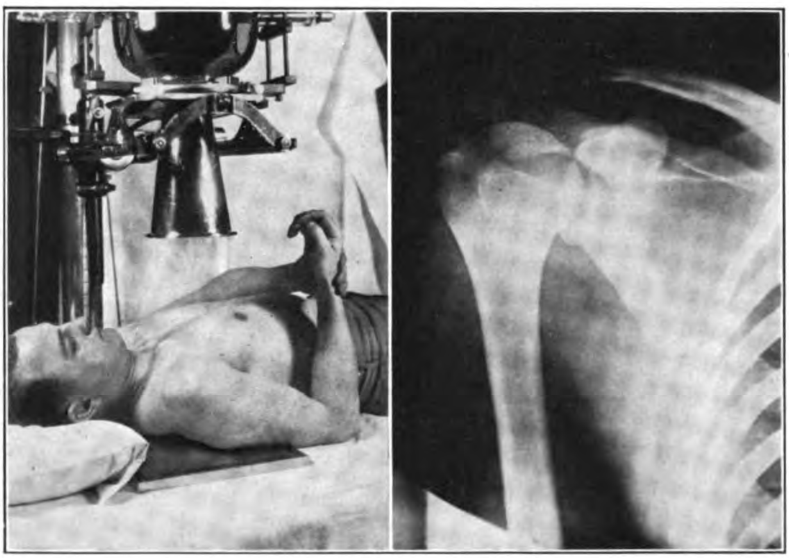

FIG. 82.—Antero-posterior exposure of the shoulder. With an injured shoulder, if it be possible to move the extremity from the position in Fig. 81 to that shown in this illustration, two views of the proximal end of the humerus may be obtained.

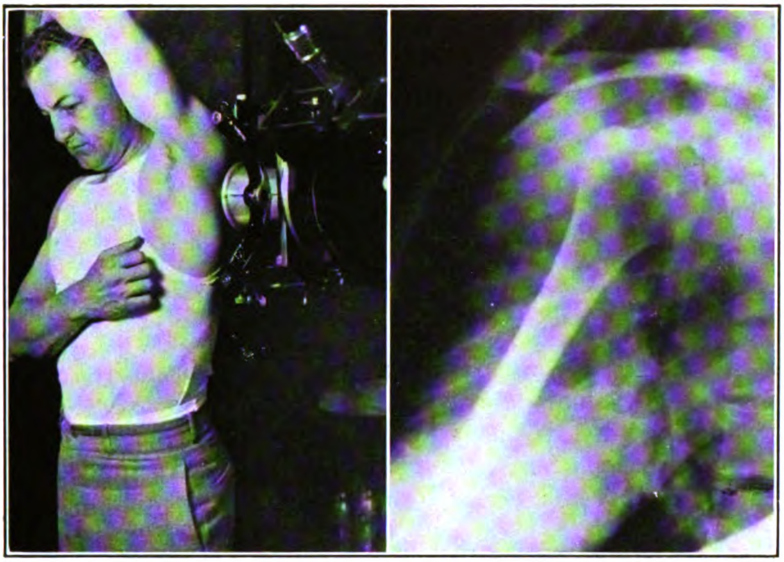

FIG. 83.—An antero-posterior exposure of the proximal end of the humerus taken through the upper part of the thorax. The exposure in Fig. 81, with the one in this illustration, gives two views of the proximal end of the humerus. In fractures these are preferable to stereoscopic films.

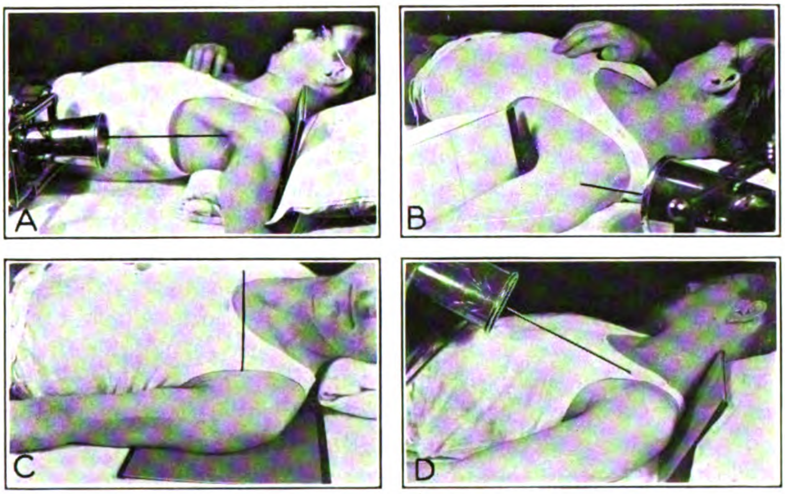

FIG. 84.—A, position for an exposure from below upward through the proximal end of the humerus and the shoulder. The arm is abducted at a right angle, the film is supported above the shoulder, the rays are directed horizontally with a slight medial angulation. B, position for a film from above downward through the proximal end of the humerus and the shoulder. The extremity is abducted at a right angle, the film is supported below the shoulder, the rays are directed horizontally from above downward with a slight lateral angulation. C, position for an exposure directly through the shoulder joint. The arm is rotated laterally, and the opposite shoulder is elevated for as much as 30 or 40 degrees. D, position for an oblique exposure from below upward and backward through the clavicle.

of the patient on sand bags or pillows until the transverse axis through the shoulders makes an angle of 30 to 45 degrees with the film. The arm should be in a position of complete lateral rotation and the central rays directed near the tip of the coracoid process (Fig. 84).

Because respiratory motion of the thorax is transmitted to the shoulder, all exposures of the shoulder region should be made during suspension of respiration.

THE CLAVICLE AND SCAPULA.

The clavicle is a rather slender bone shaped somewhat like the italic letter *f*, curving forward in its medial part and backward in its lateral part. It connects the scapula with the sternum and is the only bony connection between the upper extremity and the trunk. It is subcutaneous throughout its extent and can readily be palpated.

The clavicle was formerly said to be the most frequently fractured of any bone of the body, and now that self-starters are a part of all automobiles, eliminating fractures of the radius from motor back-firing, it probably has regained its former prominence. It may be fractured by direct violence in any part of its extent. Since the outer third of the clavicle is attached to the scapula by powerful ligaments, fractures by violence applied to the upper extremity or shoulder are uniform in location at the junction of the middle with the lateral third. Green-stick fractures in children are common. Dislocations of either the acromial or the sternal end are uncommon, those of the former being more common than those of the latter.

When the clavicle is fractured, the medial end is not much displaced; the displacement of the lateral end is always downward and forward. The constancy of the displacement and the fact that much information concerning the position of the fragments can be obtained by palpation usually make unnecessary more than a single view of the clavicle. Postero-anterior views are preferable to those made in the supine position. The patient is placed in the prone position with the upper extremity of the injured side along the trunk and the head turned toward the opposite side. The cassette, either the $6\frac{1}{2}$- by $8\frac{1}{2}$- or the 8- by 10-inch size, is placed under the injured clavicle with the long axis corresponding to that of the bone and the tube centered over the spine of the scapula behind (Fig. 85). It is important that respiration be stopped during the exposure. The supine position is one that it is often necessary to use with children, the antero-posterior views thus obtained being but slightly less valuable than those made in the prone position.

Quesada recommends two exposures of injuries to the clavicle, one obliquely from above downward and the other from below upward, the central rays for the two exposures directed at an angle

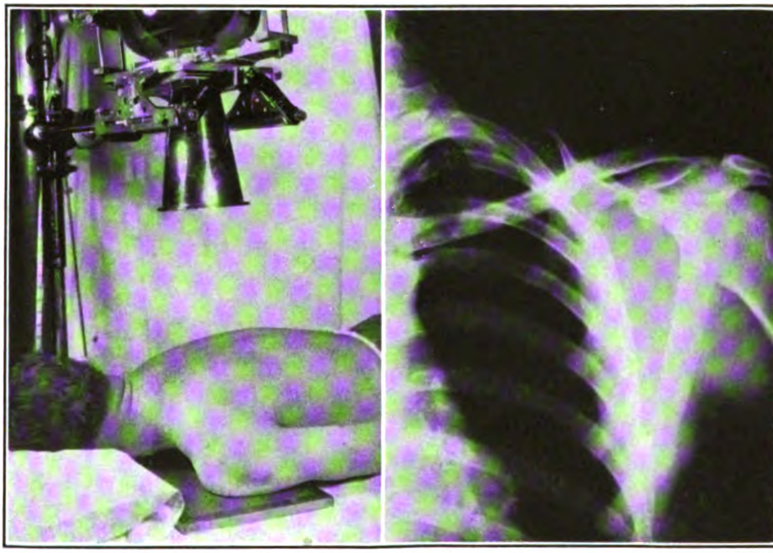

Fig. 85.—Postero-anterior exposure of the shoulder to show the clavicle. The injured side is against the cassette with the head turned over the opposite shoulder.

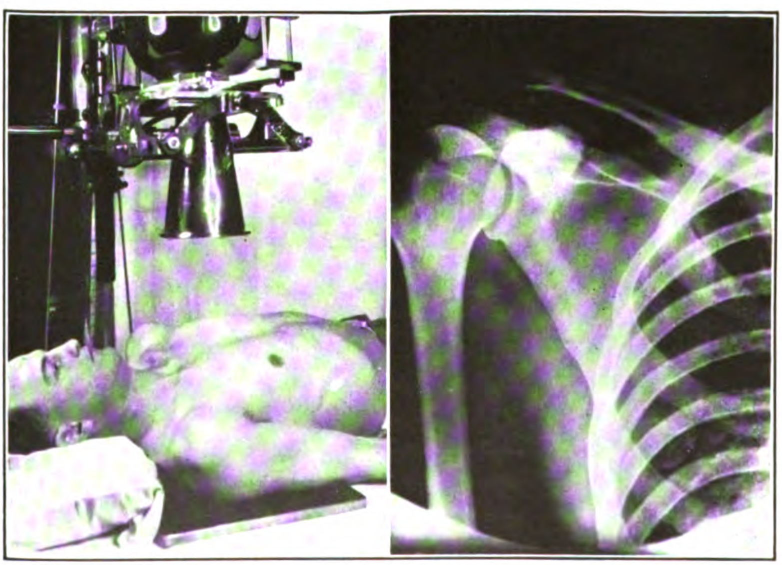

Fig. 86.—Antero-posterior exposure of the scapula. The opposite shoulder is elevated on a sand bag.

of 90 degrees with each other. Views made in this manner are at right angles to each other and accurately show all displacement that is present. He uses a device in the form of a quadrant of 90 degrees with an arm at each end to direct the central rays. The degree scale on the arm of most tube stands may be used for the same purpose (Fig. 84).

In direct postero-anterior films the sternal end of the clavicle is somewhat obscured by the shadows of the thoracic vertebræ. When this part of the bone is being examined the cassette should be placed farther medially and the rays directed at an angle of 10 to 15 degrees toward the midplane of the body. This will give views of the sternal end not covered by the shadow of the spine. Because the sternal end of the clavicle is covered by the shadows of the ribs, when seeking for evidences of disease, postero-anterior stereoscopic films should be taken.

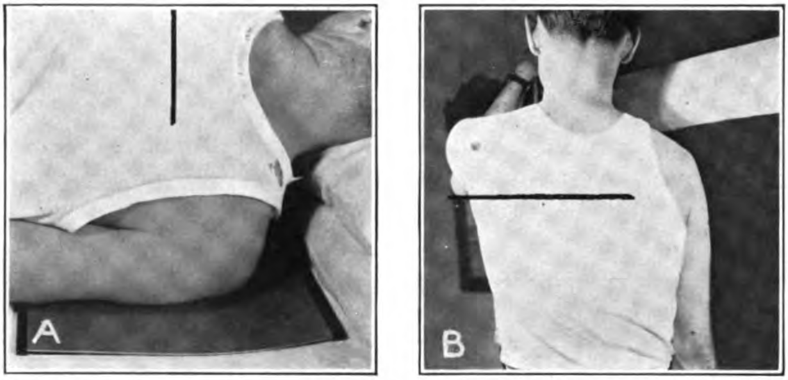

Fig. 87.—Two positions for transverse exposures through the scapula. The scapula and the shoulder are rotated forward as much as possible; A, the patient is lying in a semilateral position. This position would not be possible with an injured shoulder; B, the patient is standing. For both positions the rays are directed straight through the bone entering the middle of the vertebral border.

The scapula is a somewhat irregular, triangular-shaped bone forming the posterior part of the pectoral girdle. The spine extends across its posterior surface ending in the acromion process. The glenoid fossa is supported on a constricted portion called the neck. The coracoid process extends upward and then forward, medial to the glenoid cavity. The only connection of the scapula with the bones of the trunk is through the clavicle. It is surrounded and well padded with muscles and is freely movable. Because of its protection by muscles and its mobility, injuries to the scapula are uncommon. Fractures of the acromion, the neck, and the body both above and below the spine are occasionally encountered.

Films of the scapula should be made with the patient in the supine position with the cassette, either the 8- by 10- or 10- by 12-inch size, beneath the shoulder. The injured side should be thrown well back and the opposite shoulder elevated on a sand bag or pillow to bring the body of the bone parallel with the film (Fig. 86). To detect displacements of fractures in the antero-posterior direction, almost an exact lateral view may be made by rotating the shoulder forward as far as possible and making an exposure obliquely from behind outward and forward. In fractures this exposure is made with the patient standing, with the body turned at about an angle of 45 degrees. The central rays from the tube will enter the middle of the vertebral border of the bone and pass directly transversely through the bone. Similar films may be taken with the patient in a semiprone position if this posture is not too painful (Fig. 87).

The acromion and coracoid processes of the scapula rarely need examination. When occasion arises, in addition to the antero-posterior projection, a second view may be made obliquely from below upward and medially with the arm abducted at a right angle with the film on top of the shoulder pressed well against the neck, and with the head angled toward the opposite shoulder (Fig. 84). The coracoid process may be shown by a view from below upward through the shoulder with the tube tilted upward at an angle of 15 to 20 degrees. The lateral view of the scapula also shows these processes in profile.

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CHAPTER XIV.

THE LOWER EXTREMITY.

THE FOOT.

THE bony framework of the foot is composed of seven tarsal bones, five metatarsal bones, and the fourteen phalanges of the toes. Except those for the great toe, the phalanges are small with slender shafts and expanded extremities. The distal ends of the distal phalanges present ungual expansions for the support of the nails. Of the metatarsal bones, the first is the heaviest and also the shortest; the second is the longest. The fifth has a rough tuberosity on the lateral aspect of its proximal end.

The tarsal bones vary considerably in size, and have an irregular arrangement. They assist in forming the arches of the foot. The posterior part of the longitudinal arch, formed by the calcaneus, is shorter than the anterior, which in the tarsal region is formed by the navicular, cuboid, and three cuneiform bones. The cuneifrom and cuboid bones, with the proximal ends of the metatarsal bones, form the transverse arch. The talus (astragalus) is placed at the apex of the longitudinal arch, forming the ankle joint with the inferior articular surfaces of the tibia and fibula.

On the dorsal and lateral aspects of the foot the bones lie near the surface; on the plantar and medial aspects they are covered with thick skin and fascia and a considerable layer of muscles. On the medial aspect of the foot the tuberosity of the calcaneus, the tuberosity of the navicular, and the first metatarsal bone are all palpable. On the dorsal aspect the individual metatarsal bones can be made out nearly to their proximal extremities. The individual tarsal bones cannot be distinguished. On the lateral aspect the calcaneus is subcutaneous. The expanded proximal end of the fifth metatarsal bone can be palpated, proximal to which lies the cuboid. Except for flexion and extension of the ankle and toes, movements of the foot are limited to inversion and eversion which take place in the intertarsal articulations.

Fractures of the phalanges of the toes and of the metatarsal bones by direct violence, usually by a heavy object dropping on the foot, are common. Such injuries of the phalanges of the great toe and of the metatarsal bones are more common than similar injuries of the other bones. The metatarsal bones, usually the fifth, may be fractured by forcible inversion or eversion of the foot. Fractures of

the tarsal bones are uncommon, those of the calcaneus and talus from falls or jumps alighting on the heel being the usual form.

Roentgenography of the foot is complicated by the irregular arrangement of the bones, by the close contact of the bones with each other, making views at right angles often impossible, and by the variations in the thickness of the foot, especially in the dorsoplantar position. The more common views include the dorsoplantar view of the bones anterior to the talus, a lateral view of the entire foot, an oblique view from below upward, an antero-posterior view of the ankle showing the talus, and an oblique view from behind and above downward and forward through the posterior part of the calcaneus.

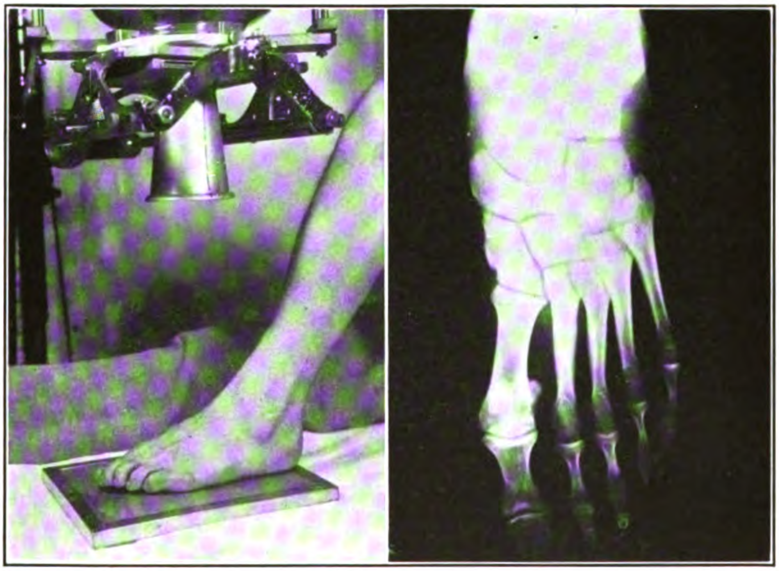

FIG. 88.—Dorsoplantar exposure of the foot. To show the toes and the proximal ends of the metatarsal and tarsal bones without over- or under-exposure, two views with different exposure factors are required.

A dorsoplantar view shows the bones of the toes, the metatarsal, and the tarsal bones anterior to the talus, including the navicular, cuboid, and the three cuneiform bones. Since the bones of the leg are above the posterior two tarsal bones, they cannot be included. This view is made by flexing the knee, extending the ankle, and resting the sole of the foot on the cassette, directing the rays perpendicularly to the surface of the cassette or at an angle of 10 degrees toward the heel with the central rays centered just lateral to the most prominent part of the instep (Fig. 88). This is over the proximal end of the third metatarsal bone or the upper surface of

the third cuneiform bone. One-half of an 8- by 10-inch film, divided transversely, is large enough for this view.

Some separation of the overlapping bones, particularly in the region of the three cuneiform bones, may be obtained if the tube also be angulated from 10 to 20 degrees from lateral to medial, or angulated toward the most prominent part of the instep. The knee is angled medially to bring the dorsal aspect of the foot more nearly parallel with the film (B, Fig. 91).

Because of the variations in thickness, it is impossible to show all of the structures with the same density on a dorso-plantar view of the foot. Exposure factors that will give the optimum density to images of the bones of the toes and heads of the metatarsal bones will result in an underexposure through the tarsal region. On the other hand, factors correct for the tarsal bones will overexpose the images of the smaller bones. For this reason, in a thorough examination of the foot it is advisable to make one exposure to show the heads of the metatarsal bones and the phalanges, and a second view on the other half of the same 8- by 10-inch film especially to show the proximal ends of the metatarsal and the tarsal bones.

Two methods are recommended to overcome the differences in thickness of different parts of the foot in the dorsoplantar direction. Clark suggests that a wedge be made of cardboard, paraffin, or some wood of even density to be placed between the sole of the foot and the film during the exposure. The wedge is 10 inches long and 7 inches wide. At the corner that fits under the little toe it is $1\frac{1}{4}$ inches thick; at the other anterior corner, to go under the great toe, it is $\frac{3}{4}$ inch thick. The corresponding posterior corners are $\frac{1}{2}$ and $\frac{1}{4}$ inch in thickness. It may be used with one side up for one foot, and turned over for the opposite foot. The other method of equalizing the densities is to use a higher voltage and a shorter exposure. The higher voltage will give rays penetrating enough for the thicker portions of the foot and the smaller quantity of rays will not give so much blackening of the toes and heads of the metatarsal bones.

In a directly lateral or transverse view of the foot, the calcaneus, talus, navicular, and cuboid are shown without being much obscured by other bones, but the cuneiform and metatarsal bones are superimposed so that all the individual images cannot be identified. For this view an area of film at least 10 inches long and 4 inches wide is required. It is made by placing the medial or lateral margin of the foot against the cassette with the tube focused halfway between the heel and tip of the great toe.

An oblique view of the foot is better than one in the lateral projection. It is made by placing the lateral aspect of the foot

against the cassette with the entire lateral aspect of the ankle and leg resting on the table. The foot is inverted as much as possible. The inversion permitted at the heel is slight, but a considerable turning of the metatarsal bones and toes is possible. In the proper position the sole of the ball of the foot is directed obliquely upward (Fig. 89). It should be held in this position with a double sand bag. The view obtained by this position will be an oblique one of the anterior bones, separating the images of the different structures so that all of them can be identified. The same size film and similar focusing of the tube are required as for the direct lateral view.

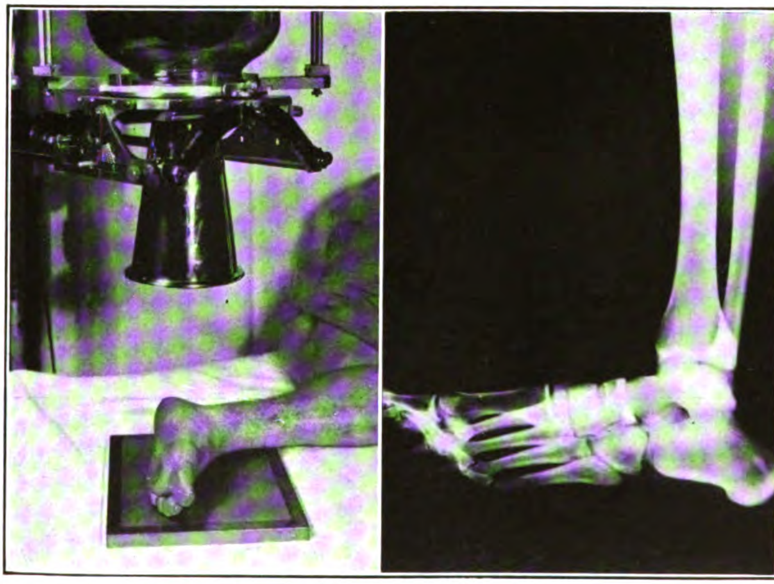

Fig. 89.—Oblique infero-superior exposure of the foot.

Because of the shape of the three cuneiform bones, their close apposition, and the fact that the proximal end of the second metatarsal bone fits between two of the cuneiform bones, it is impossible in any position to obtain clear-cut images of these bones in two directions. Fortunately injuries in this region are very rare.

The talus (astragalus) is well shown in lateral views of the foot. For the second view, since a dorsoplantar view of more than the head is impossible, dependence must be placed on a direct anteroposterior view through the ankle joint (Fig. 92). This shows the upper surfaces and lateral margins of the bone, but the neck and the head are poorly delineated.

The calcaneus is included on a lateral view of the foot, but a special view is necessary for showing it in a second projection. This

is an oblique view downward and forward through the heel. For it, the patient is placed in the prone position, with both ankles

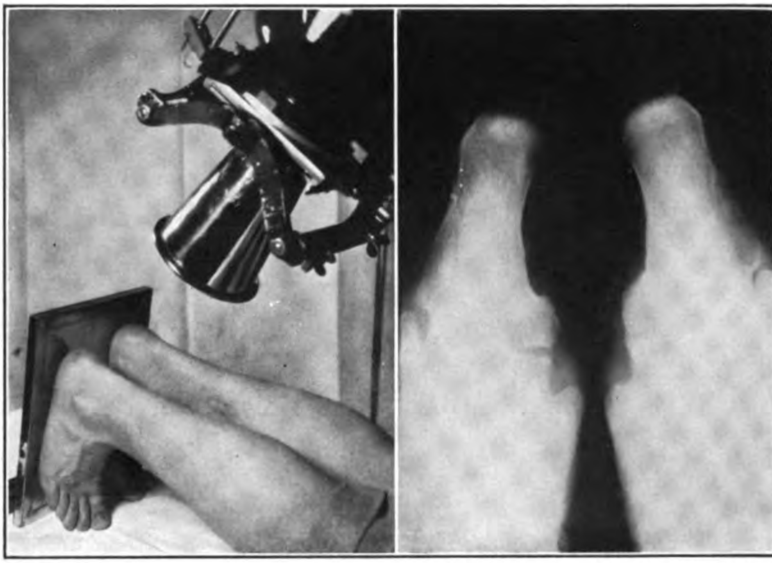

FIG. 90.—Oblique supero-inferior exposure of the heels. To show lateral displacements in fractures of the calcaneus (os calcis), this or a comparable view is necessary.

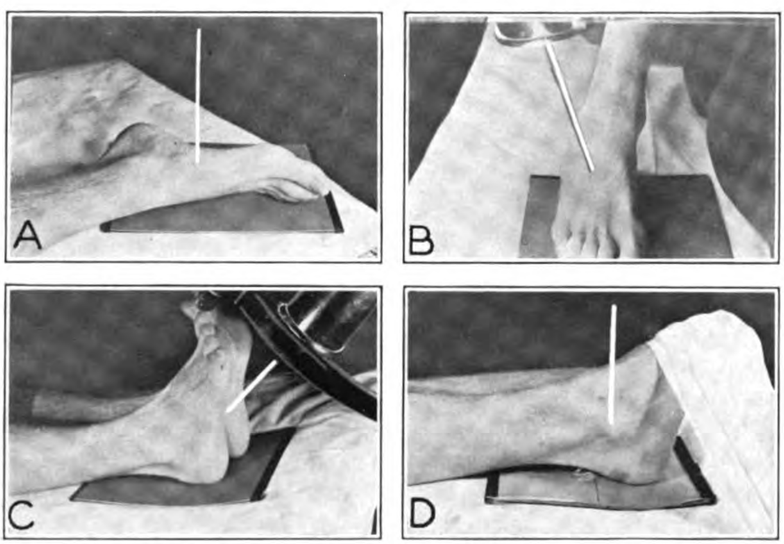

FIG. 91.—A, position for a direct lateral exposure of the foot; B, position for an oblique exposure from below upward and medially through the tarsal region. The knee is angulated medially; C, position for an exposure from below upward and backward through the heels. The tube is angulated at about 45 degrees; D, position for an exposure of the distal end of the fibula. The foot is extended and the leg medially rotated.

flexed to a right angle or as near that as the injured side will permit. The cassette, 8- by 10-inch size, is placed on end against the soles of the feet. The rays are directed downward and toward the toes at an angle of 35 to 45 degrees (Fig. 90). The tube is focused over the heels and midway between them. Both heels are included so that the injured side may be compared with the uninjured one. Since a fracture of the calcaneus is the most common of the fractures of the tarsal bones, often is a disabling injury, and the displacement may be either medial or lateral, in case of injury to the heel this view should never be omitted.

It may be that the patient cannot be turned to the prone position for this exposure of the calcaneus. An alternate method may be used with the patient supine. The film is placed back of the legs and heels. The tube is tilted, angulating the central rays upward at an angle of 40 degrees and directing them between the two insteps. The feet should be dorsiflexed as much as possible at the ankle; as much as 90 degrees is desirable. However, in case this angle cannot be obtained on the injured side, for comparable views of the two sides the angulation should be the same (Fig. 91).

THE ANKLE.

The ankle joint is a pure hinge joint between the talus (astragalus) of the tarsal bones and the lower ends of the tibia and fibula. The joint is bracket-shaped, with a horizontal part between the lower end of the tibia and talus, and two vertical parts between the talus and the articular surfaces of the medial and lateral malleoli. The malleoli at the sides of the joint are prominent and are subcutaneous, the lateral being smaller, more distinct, and projecting ½ inch farther distally than the medial. The posterior borders of the two are in the same transverse vertical plane. The line of the horizontal part of the ankle joint is ½ inch above the tip of the medial malleolus.

Injuries of the structures in and around the ankle joint are common. They occur as a result of forcible rotation of the leg on the foot, or *vice versa*, of inversion and eversion of the foot, and of violence from above downward. They vary in severity from a slight rupture of some of the ligaments and laceration of the synovial sheaths to extensive fractures of the distal ends of both bones of the leg with dislocation of the foot at the ankle joint. Perhaps the most common injury is an oblique fracture through the distal part of the fibula due to forcible rotation. A careful roentgenographic examination of many of the traumatisms of the ankle at first diagnosed as sprains will disclose bone injury.

Roentgenograms of the ankle should be made in both the antero-posterior and lateral directions. To detect injuries to the lower part of the fibula, the distal thirds of both bones of the leg should be included on both views. In the antero-posterior view the

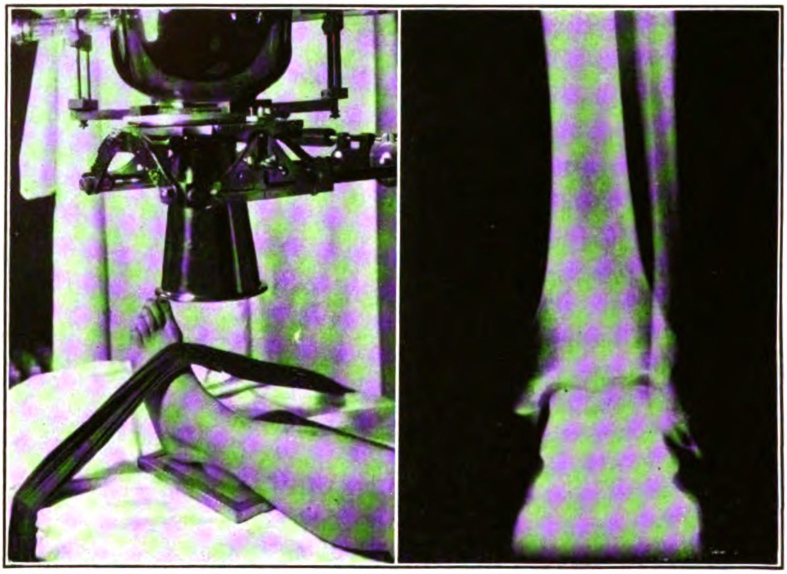

Fig. 92.—Antero-posterior exposure of the ankle.

Fig. 93.—Tibiofibular or lateral exposure of the ankle.

heel should rest on the cassette near the margin with the foot flexed to a right angle with the long axis of the leg (Fig. 92). The tube is focused over the ankle joint or slightly above this level. The lateral view is made with the lateral aspect of the ankle and lower part of the leg in contact with the cassette, with the rest of the leg in contact with the table (Fig. 93). The tube is focused over the most prominent part of the medial malleolus.

An 8- by 10-inch film divided transversely is usually sufficient for both views of the ankle. Immobilization with a double sand bag or other device is important. If another injury of the patient prevents turning the leg for the lateral view of the ankle, the leg may be elevated on a small pillow, the cassette placed on edge, and the rays directed horizontally.

THE LEG.

The tibia and fibula are the bones of the leg. The tibia is located medially and the fibula laterally and slightly posteriorly. They are of about the same length. The tibia is considerably larger and stronger than the fibula. It is largest at the upper end, gradually decreasing in size to the junction of the middle and lower thirds of the shaft and expanding again at the lower extremity. Except for the expanded extremities, the fibula is of uniform size throughout. The bones of the leg are not in the same transverse plane. The proximal tibiofibular articulation is at the postero-lateral angle of the expanded upper end of the tibia. In the middle of the leg the shaft of the fibula is in a position distinctly posterior to that of the shaft of the tibia. Toward the ankle the fibula inclines forward so that at the joint it lies lateral to the tibia (Fig. 93).

The proximal and distal ends of the fibula are palpable for a distance of from 3 to 4 inches; the middle of the bone is deeply buried in the muscles of the leg. The anterior border or shin of the tibia and all of the medial surface are subcutaneous, the latter being continuous with the subcutaneous surface of the medial malleolus.

Fractures of the bones of the leg are common. The most frequent injury is of the lower end of the fibula. Perhaps next most common are fractures of both bones of the leg at or near the junction of the lower with the middle third. The fracture of the fibula is usually somewhat higher than that through the tibia. Because of its more exposed position, the tibia may be fractured alone. Less frequent injuries may involve any part of either bone.

Roentgenograms in the antero-posterior and lateral positions are required for an examination of the bones of the leg. To show both in the antero-posterior view, the posterior aspect of the leg is placed

in contact with the cassette with the foot and toes directed vertically upward. For the lateral view the patient may be turned to the lateral position with the lateral aspect of the leg against the cassette and the foot horizontal. Because of the posterior position of the shaft of the fibula, the shafts of both bones will be shown without much overlapping of their images on both these views.

If both bones of the leg be injured and encased in a temporary dressing or splint, it often is advisable to make the lateral view by slightly elevating the limb, propping the cassette in a vertical position along the mesial aspect of the leg, and directing the rays horizontally (see Fig. 98).

For showing both bones of the leg of an adult in their entire extent in both directions a 14- by 17-inch film divided longitudinally is necessary. The tube should be centered over the middle of the leg, Because the location of the injury usually rather accurately can be determined, such a large film is rarely necessary. Usually the 10- by 12- or the 11- by 14-inch size divided longitudinally is sufficient. The region of the injury should be placed near the middle of the cassette and the central rays directed as nearly as possible through it. The fact that the fibula usually is broken at a higher level than the tibia should be remembered.

Occasionally an extremity will be encountered that is thin just above and through the ankle and thick through the prominent part of the calf and upper part of the leg. Exposure factors for films through the thinner part will not be appropriate for the thicker part. For an examination of the entire leg it then is advisable to use two films, 10- by 12-inch size divided transversely, one for the thicker and one for the thinner part, with different exposure factors for each part.

The positions of the extremity for films of the leg are similar to those for the ankle shown in Figs. 92 and 93.

THE KNEE.

The region of the knee is formed by the expanded extremities of the femur and tibia with the upper end of the fibula and the patella. The fibula articulates with the posterior part of the lateral aspect of the lateral condyle of the tibia. The patella is located on the anterior part of the lower end of the femur. In complete extension of the knee it rests on the patellar articular surface on the anterior aspect of the femur. In extension it glides over the lower end of the femur, coming to lie on a part of the inferior articular surface in front of the intercondyloid notch. At complete extension of the knee it is prominent, becoming less so as the knee is flexed.

The medial aspect of the region of the knee is formed by the medial condyles of the femur and tibia which are larger and more prominent than the lateral condyles. The lateral aspect is formed by the lateral condyles and the upper end of the fibula. The joint between the tibia and femur is located below the most prominent and bulging part of the knee. By careful palpation it may be felt as a faint but distinct groove on both the medial and lateral aspects. With the knee completely extended the joint will be located from $\frac{1}{4}$ to $\frac{1}{2}$ inch below the inferior end of the patella. To locate the joint with the knee flexed, the faint groove must be palpated.

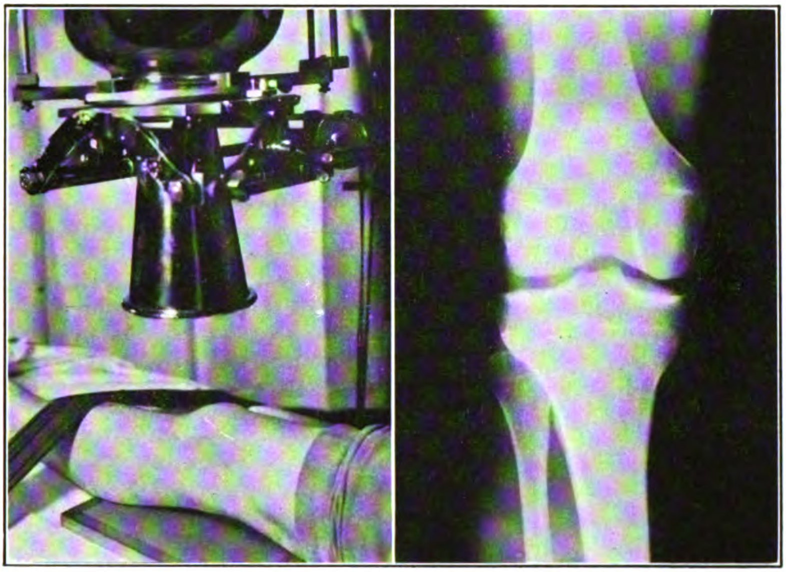

FIG. 94.—Antero-posterior exposure of the knee.

Fractures of the bones around the knee joint are uncommon; infections of the joint and infections of or trauma to the joint and the numerous bursæ around the joint probably are more frequent than fractures. Of the bone injuries, fracture of the patella, separation of the lower epiphysis of the femur, and oblique fractures through the condyles of the tibia into the knee joint probably are most frequently encountered.

Roentgenography of the region of the knee includes exposures of films in all four directions. Of these, giving views at right angles to each other, the antero-posterior and mediolateral views are most often made. The antero-posterior view is made with the joint completely extended and lying on the cassette (Fig. 94). The joint should be at the middle of the film area used so that the same

length of bones of the leg and thigh will be included. If the knee be flexed and cannot be straightened, two views must be taken, one of the bone above and the other of those below the joint.

For the mediolateral view the patient is turned to the lateral position, the lateral aspect of the knee placed against the cassette and the joint kept extended as far as possible (Fig. 95). A small sand bag or other support under the heel will assist in maintaining the true lateral position. In this position the medial condyles should be directly over the lateral with the joint in the middle of the film area. To obtain this view it may be necessary to flex the opposite thigh and leg and bring them anterior to the extremity

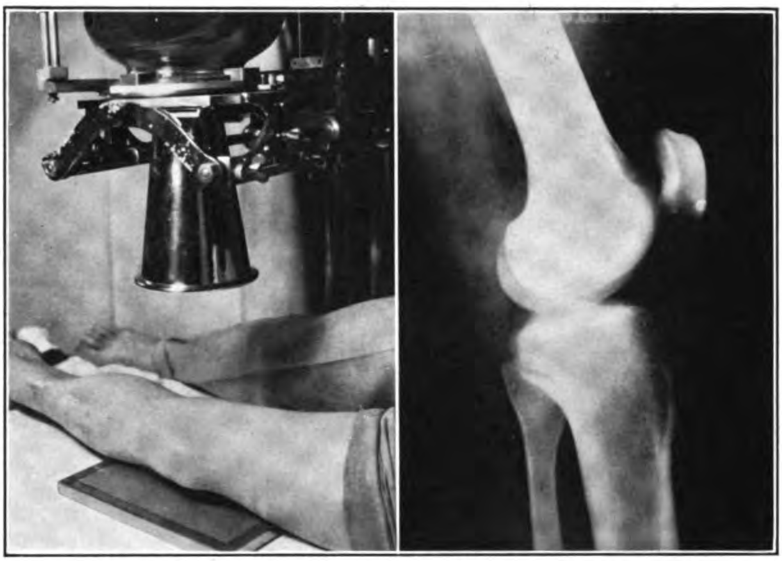

FIG. 95.—Lateral exposure of the knee. To maintain a true lateral position the heel must be elevated on a small sand bag.

being examined. In doing this the flexed extremity may be supported with pillows. Care should be taken to see that the body is not rotated toward the prone position, thus rotating the knee and giving an oblique rather than a directly lateral view.

Case recommends the postero-anterior rather than the antero-posterior as a routine position for examining the knee. It brings the patella nearest the cassette and is especially important in examining that bone. To obtain this view it may be necessary to support the thigh and leg on sand bags so that the patella is just off the cassette. For a latero-medial view the extremity may be placed on some support, the cassette placed along the medial aspect and the rays directed horizontally through the knee (see Fig. 98). The

same view may be taken with the patient in the lateral position with the knee being examined uppermost, and it, with the cassette and rest of the extremity, supported on a long, narrow, three-sided, box-like support.

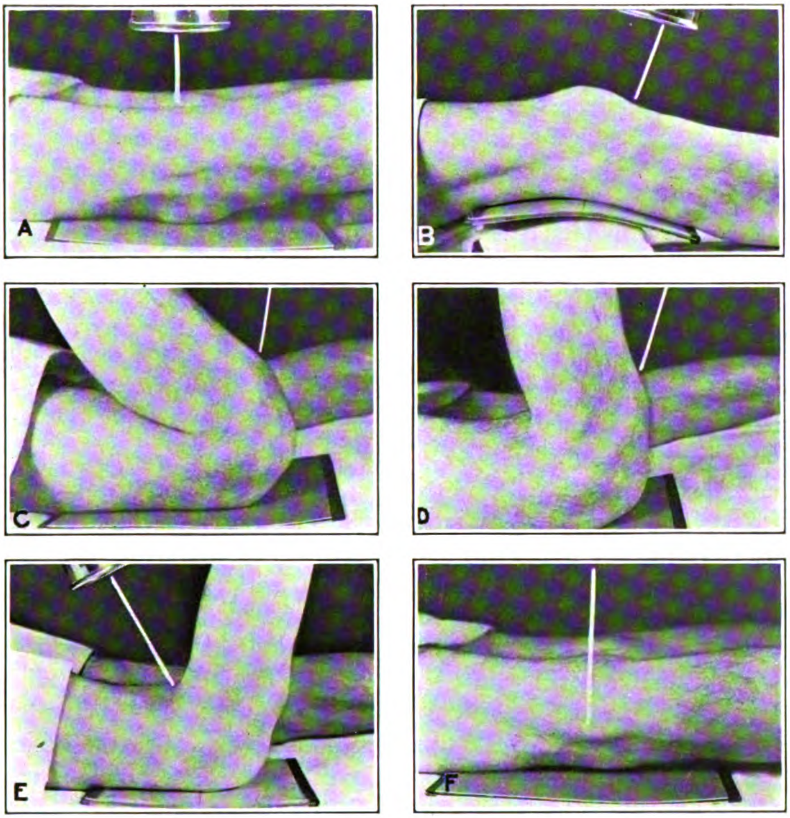

FIG. 96.—Positioning for additional exposures of the region of the knee. A, position for a postero-anterior exposure of the knee, particularly to show the patella; B, a position for an exposure through the upper end of the tibia including the spine and showing the condyles and intercondyloid notch of the femur. The knee is elevated, slightly flexed, and the rays are directed from below upward and backward; C and D, positions for profile views of the patella—C, with the knee completely flexed; and D, with the knee flexed at a right angle; E, position for the exposure of the condyles and intercondyloid notch of the femur. The knee is flexed, the rays are directed from behind downward and forward; F, position for an exposure of the proximal end of the fibula and the proximal tibio-fibular joint. The lower extremity is rotated medially, the patient is prone, and the rays are directed from behind forward through the joint.

To show all of the region of the knee in any position an area of film at least 5 by 10 inches in size must be used. This makes it possible to make the two views on a 10- by 12-inch film divided transversely or on two smaller films. The central ray should in each instance

be focused directly over the joint space. Immobilization of both lower extremities with double sand bags always is advisable.

In investigating the region of the knee for slight injuries and especially for early infection, stereoscopic films give more information than a single film. For injuries, the tube shift should be across the long axes of the bones; for infections the shift should be longitudinally across the epiphyseal lines or cartilages and the joint space, or views with the tube shift in both directions may be made on three films by the method described by Moore (page 212). Antero-posterior and lateral stereoscopic views of the same knee may be made on two 10- by 12-inch films divided transversely, using one-half of both films for each view.

Examination of the region of the knee sometimes may be necessary to show particular structures. By placing the patient in the prone position, flexing the knee on the thigh, and making an exposure tangentially through the flexed joint, an unobscured view of the patella and of the joint between it and the femur from below upward may be obtained. If complete flexion of the knee is impossible, the rays must be angulated upward at an angle of 15 to 20 degrees (C and D, Fig. 96). In direct antero-posterior and lateral projections the head of the fibula and the proximal tibiofibular joint are obscured by the tibia. By inverting the foot and slightly rotating the whole extremity in a medial direction, an antero-posterior view through these structures may be taken (F, Fig. 96). An oblique view through the knee from medial to lateral and anteriorly will serve the same purpose. By tilting the tube slightly upward in the antero-posterior position, the spine of the tibia is shown in profile. By elevating the knee 4 to 5 inches off the table, placing a small film behind the knee, and directing the rays directly through the joint, the condyles of the femur and the intercondyloid notch are shown to best advantage (B, Fig. 96).

THE THIGH.

The femur is the bone of the thigh. At its upper end it forms the hip joint. It is the longest and strongest bone of the body. Its shaft is cylindrical, of uniform thickness throughout, presenting a distinct curve anteriorly. It is entirely surrounded by muscles and is palpable only at the extremities.

Fractures of the shaft of the femur are common injuries. They are most frequent through the middle third, next most frequent through the upper third in the subtrochanteric region, and least frequent through the lower part. Before treatment the separation of fragments, overlapping, and deformity of any fracture of the

femur may be marked. The most common displacement of the broken ends of the bone is in the antero-posterior plane, the upper fragment being displaced forward and lateralward, and the lower fragment backward and medialward.

Roentgenograms of the shaft of the femur should be made in both the antero-posterior and lateral positions. The antero-posterior view is made by placing the cassette in contact with the posterior aspect of the thigh (Fig. 97). In cases of injury it is too painful to turn the patient to the lateral position for the lateral view. This view should, therefore, always be made by standing the cassette on edge along the medial aspect and directing the rays horizontally through the thigh (Fig. 98). Occasionally the patient is brought

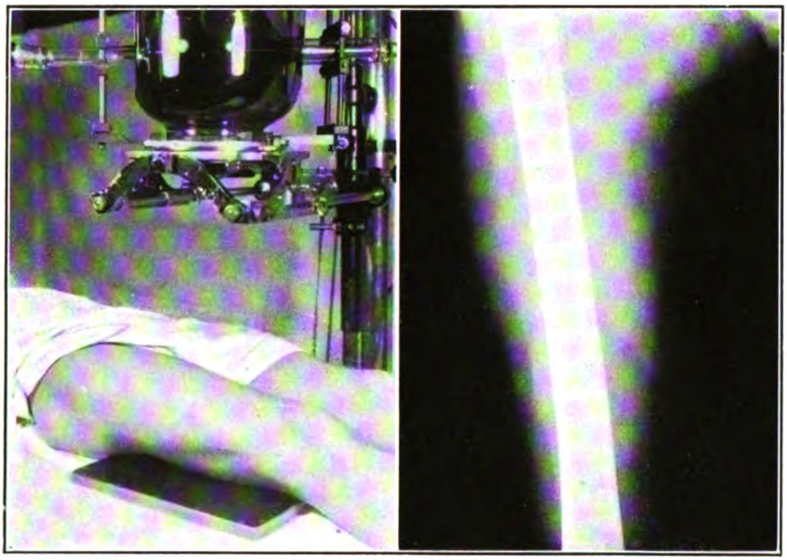

Fig. 97.—Antero-posterior exposure of the thigh.

for examination with the injured thigh in the lateral position. It is then necessary to make the antero-posterior view with the vertically placed film and horizontally directed rays and the lateral view with the perpendicularly directed rays. Since the most common displacement is in the antero-posterior plane, the lateral view should never be omitted.

The size of the film will depend on the accuracy of the location of the injury. A 10- by 12- or 11- by 14-inch film divided in either direction or two 8- by 10-inch films should be used. The central rays should be directed as nearly as possible through the site of the injury. Many injuries and infections of the shaft of the femur extend upward so as to involve the region immediately below the

trochanters. Films of these should be taken in the antero-posterior direction and stereoscopically as given under the examination of the hip. Even if the film for the lateral view, placed as high in the crotch as possible, does not include all of the injured area, the lateral view will show displacements more distinctly than the stereoscopic films and should be taken.

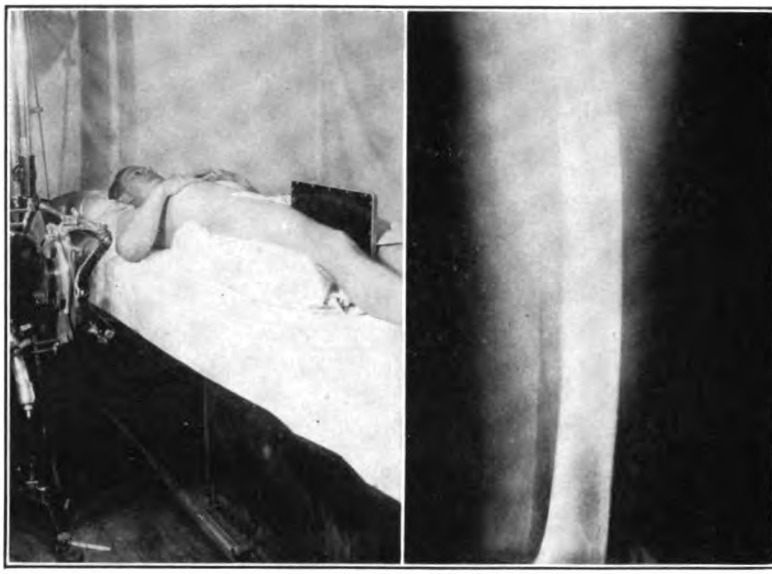

Fig. 98.—Lateral exposure of the thigh made by standing the film on edge with the rays directed horizontally. With a fracture of the shaft of the femur this method of lateral exposure is preferable to turning the patient to the lateral position. A similar procedure may also be used for lateral exposures of the ankle, leg, and knee.

THE HIP.

The region of the hip is made up of the upper extremity of the femur with the acetabular cavity and adjacent parts of the hip bone. The upper end of the shaft is somewhat expanded at its attachment to the neck of the femur. Projecting backward and upward from its upper end is the greater trochanter. The lesser trochanter is attached at the level of the lower margin of the neck and extends medially and backward. Connecting the two trochanters on the posterior aspect is the prominent intertrochanteric crest; on the anterior aspect is the much less prominent intertrochanteric line. The neck of the femur is a stout mass of bone slightly compressed antero-posteriorly, extending upward and mesialward at an angle of 120 degrees or more with the shaft. The head of the femur is spherical in shape and is attached to the end of the neck.

The acetabulum is a wide deep cavity on the outer aspect of the

hip bone. It is surrounded by a prominent margin, especially above and behind. In the lower part there is a deficiency called the acetabular notch. In the acetabulum there is a horseshoe-shaped articular surface for articulation with the head of the femur. The acetabulum is developed in three parts, one each from the pubis, ischium, and ilium. In early life these three parts are separated by cartilage. Bony union is completed about the twentieth year.

The hip joint is of the ball-and-socket variety permitting movements in all directions. Flexion and extension, abduction and adduction, and medial and lateral rotation are all represented. The most important of these to the technician is the rotation around a vertical axis. This is said to be through an arc of 45 degrees, about one-half as much as is permitted at the shoulder joint.

Since most of the upper extremity of the femur and all of the hip joint are deeply placed and not palpable from the exterior, it is important that the methods of locating the hip joint be thoroughly understood. The palpable bony points upon which this depends are the antero-superior iliac spine, the upper border of the symphysis pubis and the pubic spine, and the greater trochanter of the femur. The antero-superior iliac spine is found at the anterior end of the crest of the ilium. The crest and anterior spine can always be palpated even in persons who are very obese.

The upper border of the pubis is also always palpable. It terminates laterally at the beginning of the inguinal ligament in the pubic tubercle. The tubercle is only palpable in those who are slender. The greater trochanter is rather prominent in those who are slender but it is located at the bottom of a slight depression in those who are fat. With the muscles of the thigh relaxed the outer surface of the greater trochanter, especially the upper and posterior part, can be palpated.

The hip joint is located in the middle of a line connecting the upper part of the greater trochanter of the femur with the tubercle of the pubis. Its position in a supero-inferior direction always can be located by determining the level of the trochanter, the pubic tubercle, or the upper border of the pubic bones. For the position in the opposite direction the midpoint between the pubic tubercle and greater trochanter may be taken. One of the ways that has been used in locating the hip joint is for the operator to stand at the side of the patient, place the hand corresponding to the side being examined with the middle finger on the top of the greater trochanter, the thumb on the antero-superior iliac spine, and the index finger over the front of the hip completing the tripod, the distance between the digits being equal. With the hand in this position the index finger will be directly over the hip joint (A, Fig. 100).

From the acetabular cavity the neck of the femur extends lateralward, usually with an inclination backward. The position of the neck may be determined by the position of the foot, or preferably by determining the position of the lower extremity of the femur. The long axis of the foot is approximately at a right angle to that of the neck of the femur. The neck of the femur is directed 12 degrees anterior to a plane connecting the two epicondyles at the lower extremity of the femur, so that it may be stated that the neck of the femur is directed in approximately the same plane with the epicondyles.

Fractures of the upper extremity of the femur are common. The neck may be fractured through any part; it may be driven into the greater trochanter causing more or less fragmentation, usually with some impaction, or there may be fractures below the trochanters, involving the upper part of the shaft. Dislocations of the hip joint are rare in a roentgenological practice. Infections of the upper end of the femur and hip joint, both tuberculous and nontuberculous, are also common.

For the hip joint and the proximal end of the femur antero-posterior films, preferably stereoscopic, are taken. In cases of injury to the neck or trochanteric region of the femur, lateral views of the proximal end of the femur also are important. Whenever possible the antero-posterior exposures should be made with a Potter-Bucky diaphragm or a wafer grid.

For the antero-posterior exposure with the diaphragm, the tube is centered and so arranged that provision is made for the tube shift. This may be either transverse or longitudinal. The patient is placed with the hip to be examined over the center of the diaphragm, the location of the joint being determined by the method described in a preceding paragraph. Whenever possible the lower extremity is rotated to such a position that the neck of the femur extends laterally from the joint (Fig. 99). This will be obtained when the condyles of the femur are in the same horizontal plane or the foot is in a position of slight inversion. The extremity should be held with sand bags; the cloth of a double sand bag looped around the foot with the bags off the sides of the table will hold the extremity in the proper position. With the patient recumbent, the natural position of the extremity is that of lateral rotation with the foot everted. Films made in this position show the neck of the femur obliquely and are not as good as those on which the neck is shown in profile.

By carefully placing the patient, the hip joint may be taken stereoscopically on two 8- by 10-inch films. It is better, however, to use two 10- by 12- or 11- by 14-inch films. It should be remem-

bered that stereoscopic films made with the tube shift across the grid strips require 25 per cent more exposure than films made with the tube in the center or shifted lengthwise with the strips (page 173).

When the Potter-Bucky diaphragm is not available or cannot be used, antero-posterior stereoscopic films should be made. When immobilization can be secured, it is best to use a long exposure with a low voltage and a small cone or diaphragm. For this purpose the 10- by 12-inch size of film is large enough. If stereoscopic films cannot be made, then single films must be relied upon.

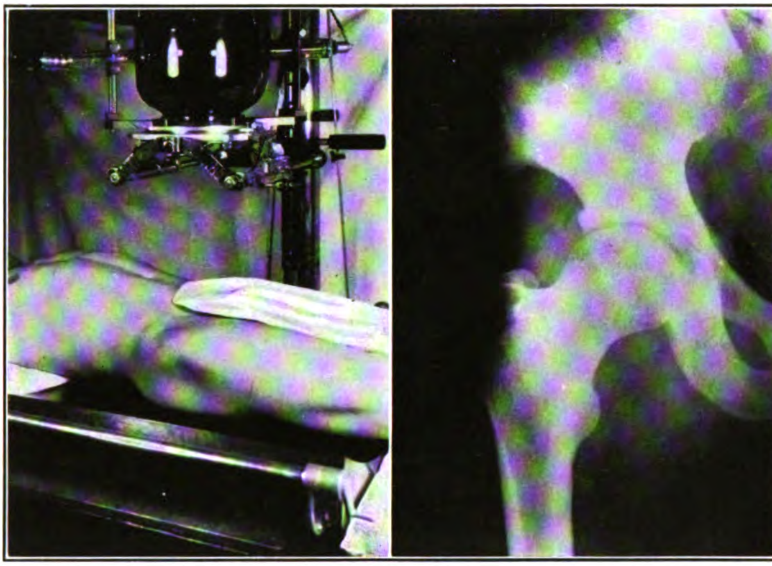

Fig. 99.—Antero-posterior exposure of the hip. To show the head and neck of the femur in profile, the toes must be directed upward or the foot slightly inverted.

When examinations are made for the purpose of examining the hip joint for infection, stereoscopic films should be taken. It is also advisable to include the opposite hip joint. Then the normal joint will be pictured and it can be compared with the one suspected of being abnormal. This examination is like that of the pelvis except that the rays are centered equidistantly from the two hip joints or over the symphysis pubis. If it be possible to flex and abduct the diseased hip, a comparison view of the heads and necks of the femora at another angle can be made by flexing the thighs and knees as much as possible keeping the feet together, then abducting the thighs and knees as much as possible, and making an antero-posterior exposure through the pelvis and hips.

Many methods have been devised for exposing lateral films

of the proximal end and neck of the femur. For showing the exact position of the fragments in fractures, such films are of the greatest importance. Leonard and George make the statement that, if intracapsular fractures of the neck of the femur be put and maintained in proper anatomical apposition, the percentage of bone

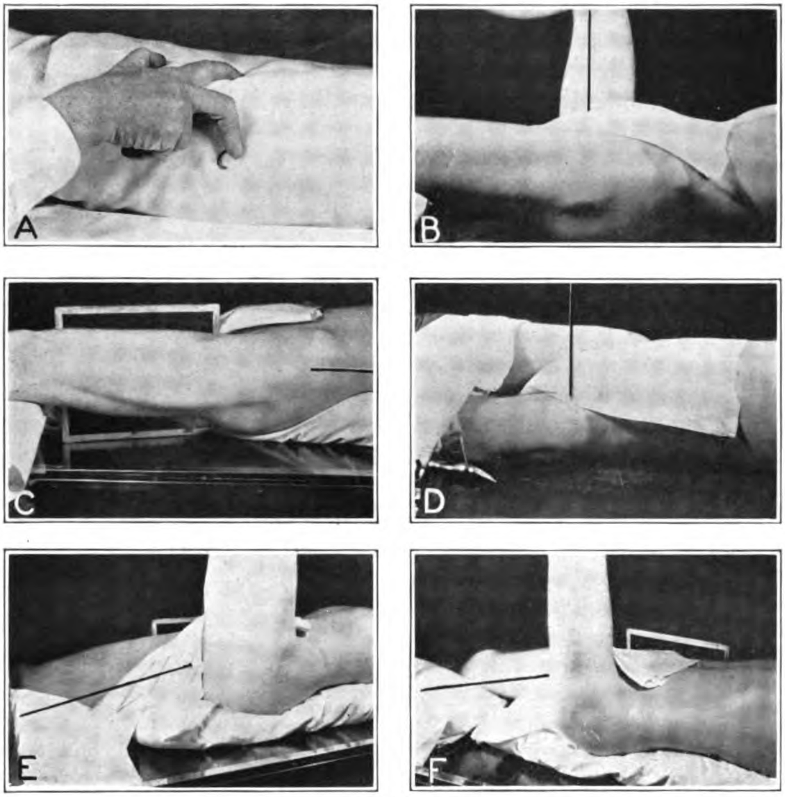

Fig. 100.—A, a method of locating the hip joint as described in the text. With the thumb on the antero-superior iliac spine, the middle finger on the top of the greater trochanter, the index finger will be directly over the hip joint if the distance between the ends of the thumb and the fingers is equal. B, position for a film through the neck of the femur. The lower extremity is flexed at a right angle and abducted as far as possible. The rays are directed vertically through the femoral neck. C, position for an exposure of the neck of the femur with the film in the perineum as far as possible, the rays directed horizontally, entering the side just below the crest of the ilium. This is the position used with curved cassettes in the perineum. D, position for the neck of the femur as described by Hickey. The lower extremity is rotated laterally and flexed at a right angle with the long axis of the trunk. The opposite lower extremity is extended and supported on pillows. The trunk is tilted backward so that the thigh is in a position of abduction as well as flexion. The central rays are directed at an angle of 20 to 25 degrees in front of the trunk, emerging through the greater trochanter. E and F, positions for an exposure of the neck of the femur with the cassette vertical along the side of the hip above the greater trochanter. The rays are directed obliquely upward and laterally across the perineum through the neck of the femur. The opposite lower extremity is flexed at a right angle and supported in this position.

union will be greatly increased and will approach the same level of good results as is found in other types of fractures.

Hickey described a method that may be used with patients that can be turned on the affected side. The patient lies on the side to be examined, with the hip flexed forming a right angle with the long axis of the trunk. It is held in this position by sand bags. The opposite lower extremity is extended as much as possible and supported on pillows. The trunk may be tilted backward so that the thigh is in a position of abduction as well as flexion, and the back supported with pillows or sand bags. The cassette is placed under the greater trochanter of the side being examined. The central rays from the tube are directed downward at an angle of 20 to 25 degrees in front of the trunk, emerging through the greater trochanter. This position was described before the invention of the Potter-Bucky diaphragm, but it may be adapted to that apparatus, especially one with a flat top (Fig. 100).

Béclère and Porcher describe seven methods, some of them credited to other writers, for making lateral views of the upper end of the femur. The one that is considered best is attributed to Costes. The patient lies in the supine position with the film on edge between the thighs and pushed as far as possible into the perineum. The tube is turned horizontally with the rays parallel to the table top. The central rays are directed downward and medially toward the film, entering the side being examined a little above the wing of the ilium. In another method, attributed to Arcelin, the normal hip is flexed at an angle of 90 degrees, the film placed on edge along the side of the hip to be examined, the tube turned horizontally, and the rays directed slightly upward from the opposite side with the central rays passing beneath the perineum (C, E and F, Fig. 100).

Leonard and George have devised a curved cassette containing double intensifying screens that may be used for exposures from above downward through the neck of the femur. With the extremity in a position of abduction, the cassette is placed on edge between the thighs with its convex surface toward the femoral neck. The rays are directed from above downward and medialward, entering just lateral to the iliac crest on the affected side.

Johnson has devised a method of making exposures through the neck of the femur without the use of accessory apparatus that gives satisfactory films. This method is based on the theoretical considerations that the angle formed by the long axis of the neck of the femur and the prolongation upward of the long axis of the shaft is 50 degrees, one-half of which is 25 degrees, and that, with the patient supine, the slope of the neck of the femur from the head to the trochanteric region is dorsalward at an angle of 25 degrees

with the horizontal. From these he concludes that the cassette should be inclined at the side of the patient at an angle of 65 degrees with the horizontal, with its center just above the greater trochanter.

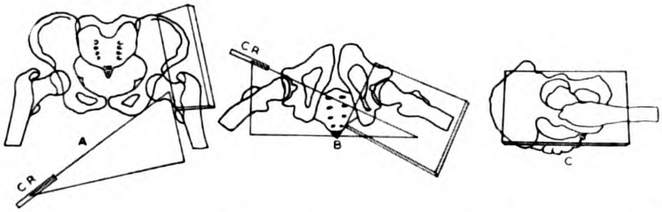

FIG. 101.—Illustrating the method of exposure of the neck of the femur by the use of an angle guide as described by Johnson. A, by the use of the guide the rays are directed upward at an angle of 25 degrees; CR, central rays: B, the rays also are directed toward the table at an angle of 25 degrees and on to the cassette tilted at an angle of 65 degrees; C, the top margin of an 8- by 10-inch film must be level with the anterior part of the pelvis or the neck of the femur will be projected off the film.

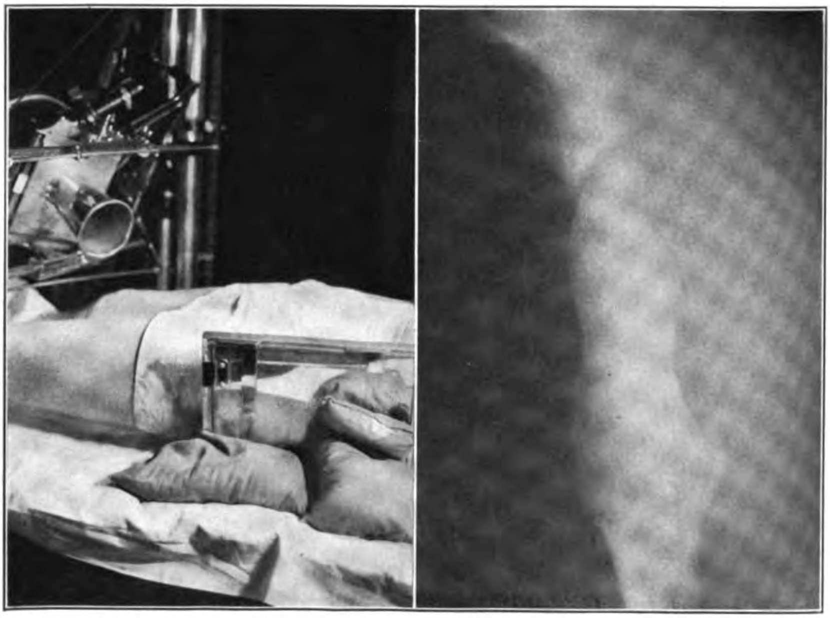

FIG. 102.—Exposure of the neck of the femur by the method described by Johnson. The tube is tilted 25 degrees toward the head and 25 degrees toward the table; the film is inclined at an angle of 65 degrees. The neck of the femur is adequately shown but the image is somewhat elongated and distorted.

The tube should be tilted upward at an angle of 25 degrees so as to give an undistorted image of the femoral neck, the central rays emerging through the greater trochanter on to the film. The tube also should be tilted backward at an angle of 25 degrees, the rays striking the inclined cassette perpendicularly. To obtain the correct

angles, he advocates the use of a right angle triangle made of heavy cardboard, with one angle of 90 degrees, one of 65, and the other of 25. With the 65 degree angle of this he inclines the cassette along the patient's side. With the base of the triangle parallel with the long axis of the shaft of the femur, he is able to direct the central rays along the hypotenuse and obtain the correct upward angulation of 25 degrees. By the use of the same angle, the central rays may be directed backward to strike the cassette perpendicularly (Figs. 101 and 102).

An 8- by 10-inch film is large enough for this exposure. A small cone should be used. An anode-film distance of 35 to 40 inches is recommended.

Experience with this method of making lateral exposures of the neck of the femur has resulted in satisfactory films. One additional precaution, not mentioned by the author, must be observed. With the cassette inclined at the side of the patient and resting on the table or bed that supports the patient, the image of the neck of the femur will be projected below the lower margin of the film. To overcome this difficulty, the patient's pelvis must be elevated on pillows, a folded blanket, or a pad, allowing the cassette to project behind the patient's gluteal region. If the patient be elevated enough to place the anterior aspect of the pelvis in the same plane with the anterior margin of the cassette (the 8- by 10-inch size placed longitudinally), the image of the neck of the femur will be near the center of the cassette (Fig. 101, C).

When movement in the affected side is permissible, a most satisfactory method of making a lateral exposure of the neck of the femur is as follows: With the patient supine, with the film under the hip, and with the tube directly above it, the extremity is flexed until it is in a position at right angles to the long axis of the trunk. Then it is abducted as far as possible. It is held in this position by an assistant while the exposure is being made. This position has been used to advantage at the completion of nailing operations for fractures of the neck of the femur, the film being made before the patient is removed from the table and while the patient is still anesthetized. This view and the routine antero-posterior exposure show the accuracy of the reduction of the injury and the placement of the nail or pins through the neck of the bone (B, Fig. 100).

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CHAPTER XV.

THE VERTEBRAL COLUMN, THORAX, AND PELVIS.

THE VERTEBRAL COLUMN.

The vertebral column is made up of the twenty-four movable vertebræ and the fixed vertebræ in the sacrum and coccyx. The movable are divided into seven cervical, twelve thoracic, and five lumbar. Except the first and second cervical which are atypical, each vertebra has the same parts. The body, directed forward, is a mass of bone shaped like a short segment of a flattened cylinder. The body supports the vertebral arch posteriorly. This consists of the roots of the vertebral arches (pedicles) and the laminæ. From the sides of the body and from the vertebral arch there spring seven processes. Two of these, the transverse processes, are directed lateralward; one, the spinous process, extends either directly or obliquely posteriorly; and the other four, the articular processes, are directed, two upward and two downward, for articulation with similar processes of the vertebræ above and below (Fig. 103).

With the exception of the upper and lower thoracic, the bodies of the vertebræ gradually increase in size from the second cervical to the fifth lumbar. In the cervical region the spinous processes are directed nearly horizontally and are bifid at the tip. Those of the thoracic vertebræ have more of an inclination downward. This increases from the first to the eighth, then decreases rapidly to the twelfth which is nearly horizontal. Those of the lumbar region are quadrilateral and directed horizontally backward. The spaces between the spinous processes are greatest in the lumbar region. A slight lateral inclination of one or more of the spinous processes is not unusual and must not be mistaken for injury. The transverse processes partly spring from the sides of the bodies in the cervical and from the vertebral arches in the other regions. They have a distinct posterior inclination on the thoracic vertebræ, but are directed more nearly transversely in the cervical and lumbar regions. They are most prominent in the upper thoracic and in the lumbar regions. The articular surfaces of the articular processes are placed in a transverse plane in the cervical and thoracic, gradually changing to an antero-posterior direction in the lumbar region. The joints between the articular processes of the fifth lumbar and the sacrum are usually obliquely placed.

The vertebral column presents distinct curves in the antero-

posterior plane. The curve extends forward in the neck, backward in the thorax, and forward again in the lumbar region (Fig. 104, B). A slight lateral curvature also is found so often that it may be considered a normal finding. The convexity of this curve usually is to the right at about the fourth thoracic vertebra.

In the adult the sacral and coccygeal vertebræ, five and four in number respectively, are fused into two bones. The sacrum is triangular in shape, widest at the superior part, rapidly tapering inferiorly. It joins with the fifth lumbar vertebra at a distinct angle with a prominence, the promontory, projecting anteriorly. It is obliquely placed, with a marked posterior curve. On the sides

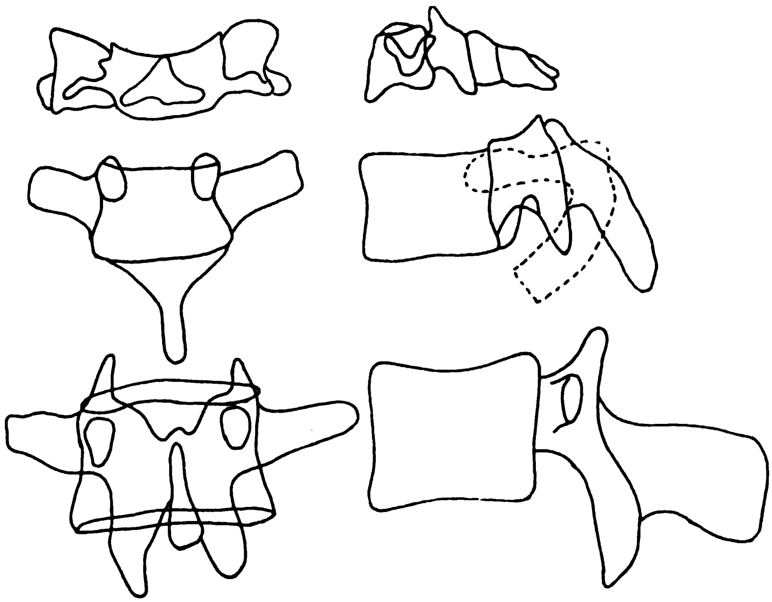

FIG. 103.—Outline tracings of the fourth cervical, seventh thoracic, and fourth lumbar vertebræ as they appear on antero-posterior and lateral roentgenograms.

of its lateral masses it has large, rough, articular surfaces for articulation with the ilia to complete the pelvis posteriorly. The coccyx is much smaller and is composed of four rudimentary segments of which the upper is the largest and the lower the smallest.

Injuries of the vertebral column, while not common, are becoming more frequent because of the increase in the number of severe injuries due to automobile accidents. The usual type consists of a compression fracture of one or more of the bodies of the vertebræ from hyperflexion of the spine. These may be complicated by fractures of the transverse processes or other small parts of the bones. Such injuries are most frequent at the junction of the more

movable with the less movable portions of the column. Fractures of the first lumbar vertebra and of those on each side of it are more common than all other spine injuries combined. Wallace found that 70 per cent of 82 instances of spine injury were to the bodies of the twelfth thoracic and first two lumbar vertebræ.

Dislocations of the vertebræ are rare. The cervical region is the most common site. The usual form is a dislocation forward of a vertebra on the one below, often accompanied by fractures of some of the processes. More or less displacement of the vertebræ is present in the more severe injuries in other localities.

Disease of the bodies or other parts of the vertebræ are rare lesions. They are most often a tuberculous infection or metastasis from a distant malignancy. Pain in the back, usually in the lumbar portion, is a frequent symptom that calls for roentgenographic examination of the vertebral column. Congenital anomalies occur most frequently in the lumbosacral region, involving the first piece of the sacrum or the fifth lumbar vertebra, and are probably a cause of symptoms in the lower part of the back.

The extent of the vertebral column and the depth at which it is placed make the exact location of a particular segment often a difficult procedure. To assist in placing patients and films for examination of the spine, a number of landmarks which give the approximate location of certain vertebræ may be used. These are given below, taken mostly from Rawling. While there probably is some variation in the exact location of the vertebræ depending on body habitus, those given are adequate for the purpose for which they are here intended (Fig. 104).

First cervical—Level of the hard palate.

Second cervical—Level of the free margin of the upper teeth.

Second to third cervical—Level of the hyoid bone.

Fourth cervical—Level of the upper part of the thyroid cartilage.

Sixth cervical—Level of the cricoid cartilage.

Disk between the second and third thoracic—Suprasternal notch.

Disk between fourth and fifth thoracic—Junction of manubrium and body of sternum.

Disk between ninth and tenth thoracic—Sternoxiphoid junction.

First lumbar—Transpyloric plane, midway between umbilicus and sternoxiphoid junction.

Disk between third and fourth lumbar—Umbilicus.

Fifth lumbar—Plane connecting anterior superior iliac spines.

With the patient in the lateral position, in addition to the above landmarks, there are a few others that are useful. The transverse process of the atlas can be palpated by deep pressure just below and in front of the tip of the mastoid process; the most

prominent spinous process at the root of the neck posteriorly is that of the seventh cervical vertebra; the lower border of the lateral part of the costal margin usually is opposite the third lumbar vertebra; a line connecting the highest points of the iliac crests, which can be determined by palpation, crosses the body of the fourth lumbar vertebra, and the lumbosacral junction is about 1½ inches below the highest point of the iliac crest and about midway from anterior to posterior on the lateral aspect of the ilium (Fig. 104, B).

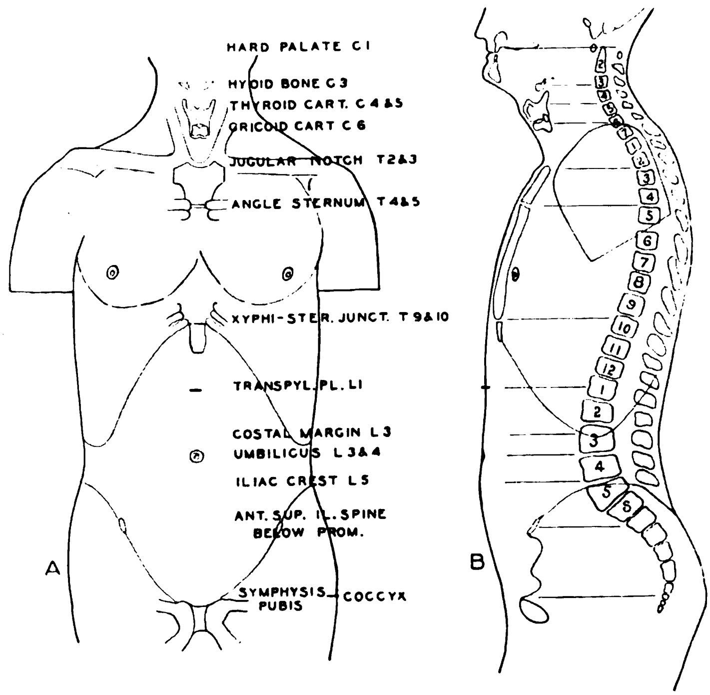

FIG. 104.—Landmarks for exposing different parts of the vertebral column: A, for antero-posterior exposures; B, for lateral exposures. The letters C, T, and L, followed by numbers refer to particular cervical, thoracic, and lumbar vertebræ.

Roentgenograms of the vertebral column most often are made in the antero-posterior and lateral directions and less often in an oblique direction. Since the most common injury is one of crushing of the body that is shown better on lateral than antero-posterior films, lateral views always should be taken. Hickey, Bowman, Brailsford, and Balensweig all emphasize the importance of lateral views, the last named two even stating that a lateral view is of more importance than an antero-posterior one. In antero-posterior views images of the different parts of each vertebra are more or less superimposed. Thus the shadows of the body, the roots of the vertebral

arches, the laminæ, the spinous processes, and, to a less extent, those of the articular processes, may be in the same area. Only the transverse processes project lateralward to the sides of the images of the other parts, and in certain regions parts of the images of the laminæ, the articular and the spinous processes, project across the shadows of the intervertebral disks (Fig. 103).

In lateral views the outlines of the bodies and spinous processes are seen in profile, but those of other parts are superimposed so that differentiation of those of opposite sides is impossible (Fig. 103). Oblique views are taken usually for special purposes, but they, too, show a superimposition of shadows of some parts of the bones.

Throughout most of the vertebral column, roentgenography is complicated by the presence of other structures that are radiopaque and cast shadows on the films. The mandible in the upper cervical region, the sternum, ribs, heart and aorta, the pectoral girdle and shoulders in the thoracic region, and the lower ribs and the alæ of the ilia in the lumbar region complicate both the exposure and interpretation of films of the vertebral column.

Roentgenography of the vertebral column is further complicated by distortion in shape of the bodies and other parts of the bones. This especially is true if any considerable portion of the spine be included on a large film. Those bodies in the center of the film, in the path of the central rays, will be shown in nearly their exact size and shape. The rays will pass directly through the intervertebral spaces showing them as clear zones on the films. Other vertebræ, either above or below the center, will be increasingly distorted as they are removed from the path of the central rays; the intervertebral spaces will be overlapped by the images of the bodies, and there will be overlapping of the images of other structures. In the cervical and lumbar regions the presence of the anterior curvature makes distortion in shape more pronounced than it is on films of the thoracic region where the curvature is posterior.

The anatomical peculiarities and the difficulties encountered in roentgenography of the spine enumerated above indicate certain general principles that should be observed in making roentgenograms of any part of the vertebral column. The complexity of the structure of the vertebræ makes necessary the use of stereoscopic films, at least in the antero-posterior direction, giving perspective that enables the examiner to look in front of and through the images of certain parts to examine the others. The superimposition of the shadows of other opaque structures on those of the vertebræ is an additional factor favoring the use of stereoscopic films and the employment of various positions to obtain films the images on which are as nearly as possible free from such shadows. The greater fre-

quency of injury and disease of the bodies requires the exposure of lateral films so that these parts may be seen in profile and compared one with another. The distortion in size and shape, especially when large films are used, suggests that it is better to make examinations on relatively small films, including only a small area on each, and, if the examination of a large extent of the column be necessary, exposing more than one set of films.

Thoroughness with which roentgen examinations of the spine should be made depends on the complaint and the condition of the patient. An ambulant patient with minor complaints and with little or no disability may be subjected to any sort of an examination to cover fully the regions suspected of being diseased or injured. Under such conditions there is little likelihood of aggravating any condition that might be present. If, however, there are indications that a severe injury may have been sustained, all examinations should be planned and made with the greatest care. In many instances even the slightest aggravation of the bone trauma may result in serious spinal cord injury and great damage to the patient. If it be necessary to move the patient, the chief precaution should be to keep the body absolutely straight. This applies particularly to the regions of the cervicothoracic, the thoracolumbar, and the lumbosacral junctions. Most injuries are due to hyperflexion—bending one part of the spine forward on another—and bending of the spine is particularly to be avoided.

When there is a possibility of severe injury, the simplest survey examination should be made. This may be limited to anteroposterior films of the thoracic and lumbar regions and a lateral film of the cervical vertebræ. The examination of these films will determine whether or not a dangerous injury is present, and subsequent examinations may be planned with the findings of the preliminary survey in mind.

THE CERVICAL VERTEBRÆ

The atlas or first cervical vertebra is ring shaped. Laterally are situated two masses that articulate with the condyles of the occipital bone superiorly and with the second cervical vertebra inferiorly. There is a shorter anterior arch between the lateral masses. The ring is completed by a longer posterior arch extending from one lateral mass to the other. The vertebra has no spinous process but there are prominent transverse processes. The second cervical vertebra (axis, epistropheus) is distinguished by the prominent odontoid process that projects upward from the body and fits into the anterior arch of the atlas. The transverse processes of the axis are insignificant, but the spinous process is long and thick.

Injuries of the cervical vertebræ most often occur in the lower part of the series involving the fourth, fifth, or sixth segments. These are compression fractures of the bodies with anterior dislocations caused by trauma flexing the head onto the chest. Next most frequent are injuries in the occipito-atlantal and atlanto-axial regions caused also by trauma from the head transmitted to these regions.

Roentgenological examinations of the cervical spine are complicated by the jaws and the teeth anteriorly and the base of the skull above and posteriorly. Unobstructed views of the joints between the occipital bone and the atlas cannot be made. On the postero-anterior view much like that of the Granger position for the nasal sinuses (see p. 331), these joints and those between the lateral masses of the atlas and the body of the axis will be shown through the maxillary antra. The head should not be tilted quite as much as for the Granger sphenoid position, the angulation being 10 degrees instead of 17. The position can be closely imitated by placing the patient's head in the nose-forehead position, the line from the lateral canthus of the eye to the external auditory meatus perpendicular to the film, and the central rays directed into the back of the neck to emerge through the antra (A, Fig. 105).

Antero-posterior exposures may be made of these joints through the orbits. The patient is placed supine with the film under the back of the head and the upper part of the neck. The line from the outer canthus of the eye to the external auditory meatus is perpendicular to the center of the film. The central rays are directed through the bridge of the nose. Then the head is turned until one orbit is directly under the tube. One exposure is made in this position; then the patient is turned in the other direction and the other side is exposed on another area of film. The odontoid process of the axis is well shown on these exposures. Only small film sizes are required—the 6½- by 8½-inch size for the postero-anterior projection and half of a film of the same size for each of the antero-posterior views (B, Fig. 105).

Because of the presence of the mandible, all the cervical vertebræ cannot be shown on one antero-posterior film. George described a method of making such views of the first two through the open mouth. The patient is placed on the table in the supine position without a pillow. The head is adjusted until a line from the edges of the upper incisor teeth to the tip of the mastoid process is perpendicular to the table (Fig. 106). The cassette is placed under the head, with the external occipital protuberance on its upper margin. The mouth is opened as far as possible and held open by placing a large cork between the teeth. The central rays are directed

perpendicularly to the film through the center of the open mouth. Immobilization of the head with a double sand bag across the forehead and suspension of respiration during the exposure are necessary.

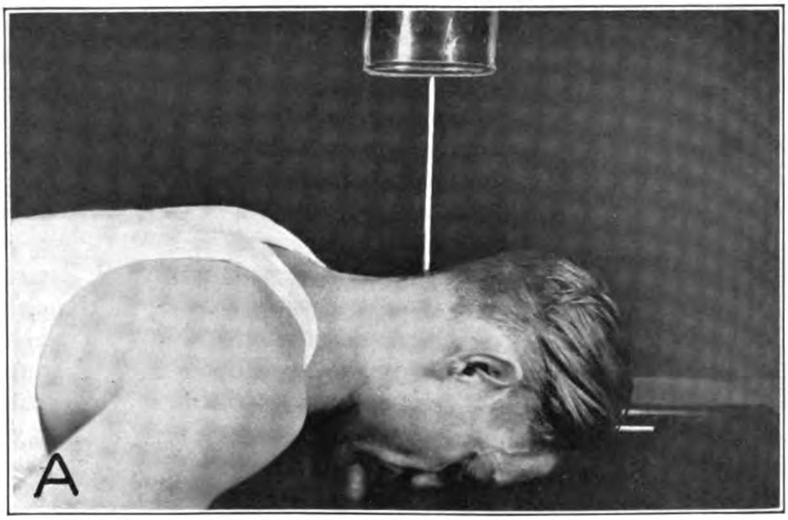

FIG. 105.—A, position for exposure of the atlanto-occipital articulations from behind forward. The nose and chin are pressed against the cassette, the line from the lateral margin of the orbit to the external auditory meatus is perpendicular to the film surface. The rays are directed from behind forward to emerge through the maxillary sinuses. B, position for an oblique antero-posterior exposure through the atlanto-occipital articulations. A line from the lateral margin of the orbit to the external auditory meatus is perpendicular to the film surface. The tube is first centered over the bridge of the nose between the orbits, then the head is rotated to one side so that the rays pass directly through the orbit. An exposure of each side is necessary. The odontoid process of the axis is well shown on these films.

The smaller films, either the 5- by 7- or $6\frac{1}{2}$- by $8\frac{1}{2}$-inch size, are large enough for this exposure.

For antero-posterior views of the lower cervical vertebræ, to straighten out the anterior curve as much as possible, the upper

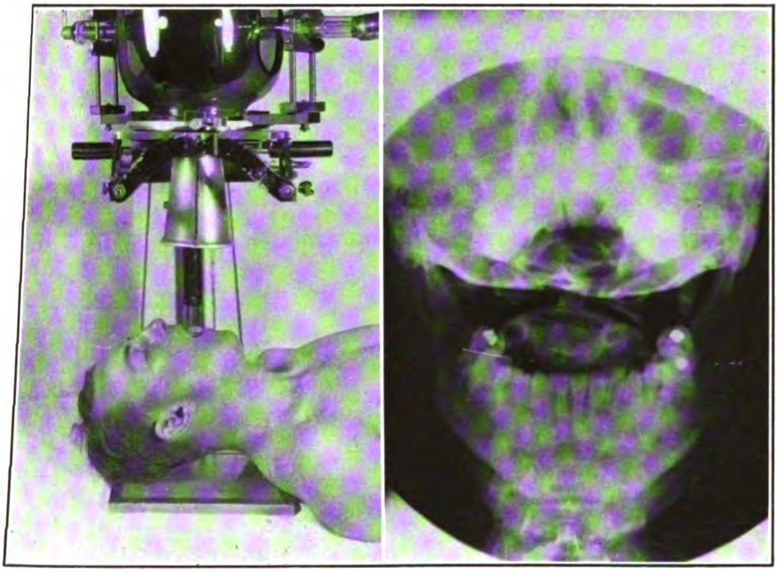

FIG. 106.—Antero-posterior exposure of the first and second cervical vertebræ through the open mouth. The mouth is held open by a large cork; a line from the edge of the upper incisor teeth to the tip of the mastoid is perpendicular to the cassette.

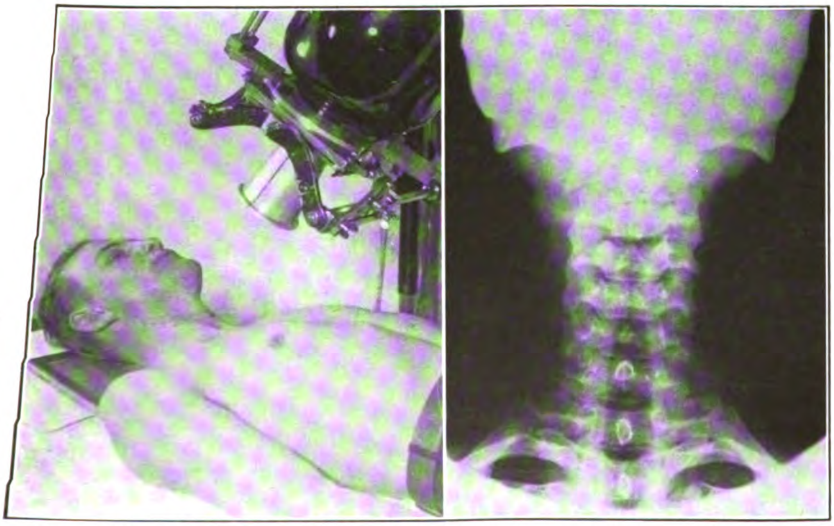

FIG. 107.—Antero-posterior exposure of the lower cervical vertebræ. In this instance the lower six are shown. The top of the cassette is elevated on a sand bags, the chin is extended, the tube is tilted toward the head, and centered over the most prominent part of the larynx.

border of the cassette or plate-changing tunnel is elevated with an inclined block or with a sand bag, the upper border of the film being as high as the external occipital protuberance (Fig. 107). The chin is elevated and the head immobilized with a double sand bag. The tube is tilted so that the rays strike the film perpendicularly or are directed slightly obliquely upward. The central ray is directed through the most prominent part of the larynx. Films of the $6\frac{1}{2}$- by $8\frac{1}{2}$-inch size will include all of the lower cervical vertebræ and the upper one or two thoracic vertebræ as well. Suspension of respiration during exposure is necessary. This exposure may be made with a Potter-Bucky diaphragm. The tube should be tilted

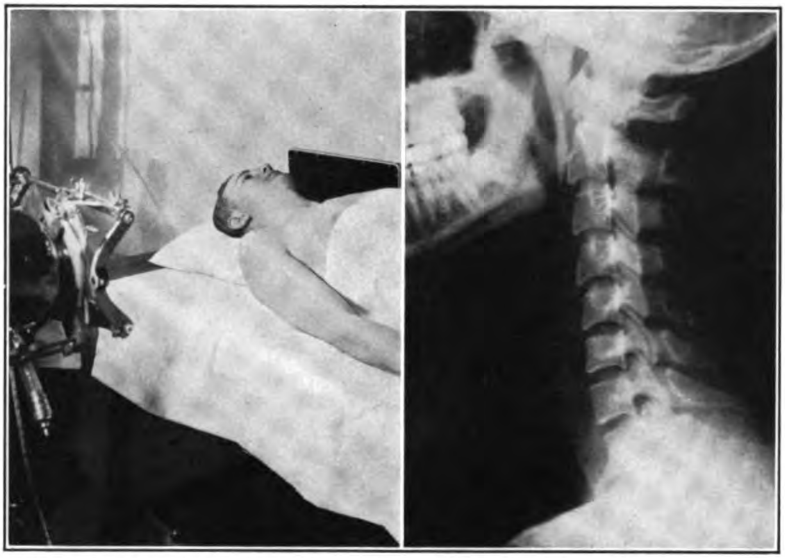

FIG. 108.—Lateral exposure of the cervical and first thoracic vertebræ. The cassette is placed parallel with the neck and along the shoulder; the shoulders are depressed as much as possible; the anode-film distance is 5 feet.

10 degrees toward the head. By such a tilt the rays pass more nearly through the intervertebral spaces. In these antero-posterior exposures it is possible to elevate the chin too much and displace the occipital bone downward over the upper part of the cervical vertebræ.

Lateral views of the cervical spine present the same difficulty as do the antero-posterior views except that the trouble comes from overlapping of the lower cervical vertebræ by the shoulders. By placing a patient in the lateral position with the head supported on a block or pillow and the cassette under the neck, pushed as far down against the shoulder as possible, lateral views of the upper cervical region can be secured. A procedure for exposing lateral

films that will show all of the cervical vertebræ and the first thoracic in the lateral projection is the one recommended by Grandy.

The essential features of this method are the placing of the film, not along the side of the neck, but parallel with the neck at the side

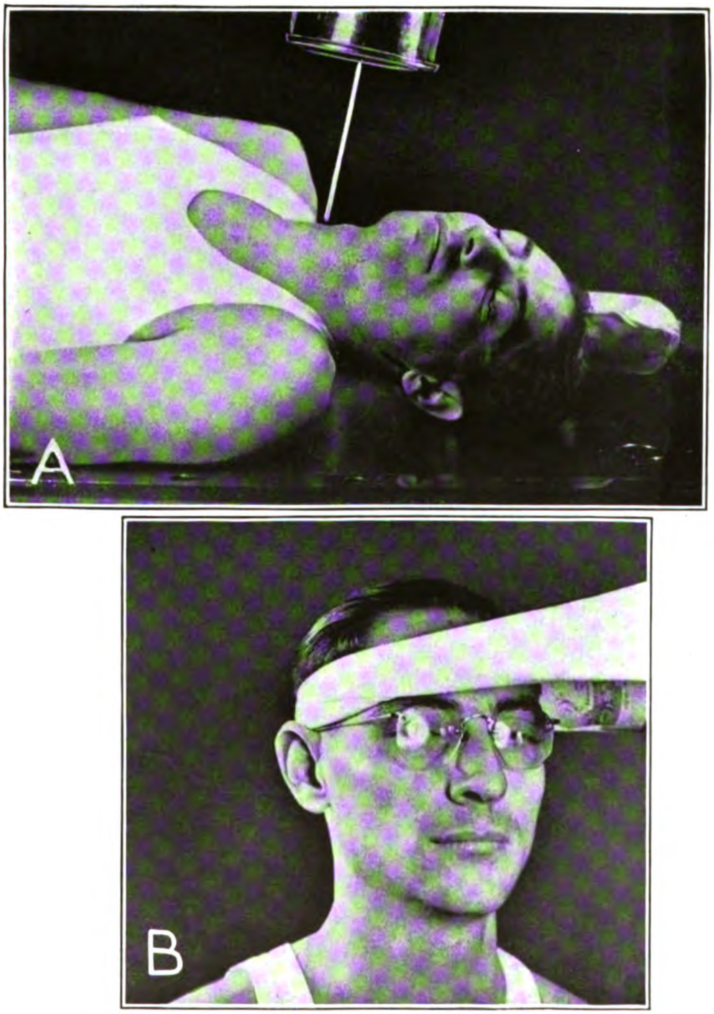

FIG. 109.—A, position for an exposure of the intervertebral foramina of the cervical spine. The patient is rotated to a position of 45 degrees with the table or film, the tube is angled 10 degrees toward the feet and the rays centered through the middle of the cervical region. B, position for a lateral exposure of the cervical spine with the patient erect. The patient is sitting with the chin and face directly forward, the shoulders are depressed as much as possible, the film is held in a vertical film holder reaching below the shoulder, the rays are directed horizontally into the middle of the neck, the anode-film distance is 5 feet. This position also is satisfactory for the larynx and soft tissues of the neck in a lateral projection.

of the shoulder, and using an anode-film distance of 5 feet or more. Such exposures may be made with the patient sitting or in the supine position. In the sitting posture the patient is seated at the side of a cassette-holding device with the head erect and supported by a headrest fastened to the back of the chair, a head clamp, or some such device. The shoulder is pressed firmly against the cassette holder and both shoulders are depressed as much as possible. In the supine position the patient lies on the table with a flat, nonradiopaque pillow placed lengthwise under the head, neck, and shoulders (Fig. 108). The cassette, standing on edge, is placed along the side of the shoulder and parallel with the neck. The shoulders are depressed as much as possible by having the patient reach downward with the upper extremities at the sides of the trunk.

In either case the tube is turned horizontally, the central rays being directed toward a point halfway between the pinna and the shoulder. An anode-film distance of 5 to 7 feet is required. A 10- by 12-inch film should be used, with its long axis parallel with the neck and its upper border above the pinna. Because the shoulders are elevated during inspiration, respiration should be suspended at full expiration. The time of the exposure may be calculated according to the instructions given under Experiment 5 on page 126.

When the patient can sit up and when films of the proper size can be placed in a stereoscopic plate changer, stereoscopic lateral films of the entire cervical spine can be exposed while the patient is suspending respiration at the end of expiration. These films are the most informative that can be made of the cervical vertebræ. A block of wood, a roll of bandage, or a paper mailing container of the correct length between the side of the head and the surface of the changer, with the head supported by the immobilizing band of the changer, will maintain the head in proper position for lateral exposures in the erect posture (B, Fig. 109).

Oblique films of the cervical spine occasionally are of value. These may be taken from either or both sides with the rays directed into the anterior and lateral aspect of the neck and emerging at the posterior lateral aspect of the opposite side. The rotation of the body is through a horizontal arc of 45 degrees. The patient may be either in the erect or horizontal position. If the rays be directed at an additional angle at 15 degrees toward the feet of the patient, the lateral projection will show the intervertebral foramina to best advantage (A, Fig. 109).

THE THORACIC VERTEBRÆ.

Films of the thoracic vertebræ may be taken in the antero-posterior, the oblique, and in the directly transverse direction. The antero-posterior films should present no special difficulty. They

always should be taken stereoscopically and with the use of the Potter-Bucky diaphragm (Fig. 110). The point for locating the center of the thoracic spine on the anterior chest wall over which the tube should be centered is in the midline, one-third of the distance from the sternal angle to the sternoxiphoid junction (Fig. 104, B). The patient should suspend respiration during the exposures. Large films are required, either the 14- by 17-inch or the 7- by 17-inch films placed with the spine in the longitudinal axes of the films.

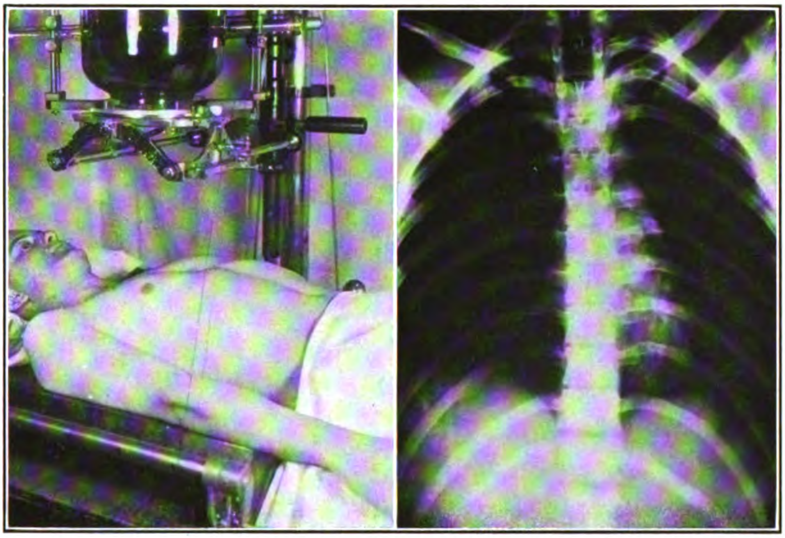

FIG. 110.—Antero-posterior exposure of the thoracic vertebræ. The tube is centered just below the angle of the sternum.

For the oblique position, the patient lies on the Potter-Bucky diaphragm with the left side of the back in contact with the top of the diaphragm and the body rotated at approximately the halfway position between the supine and left lateral positions. The left shoulder and upper extremity are brought forward and the right upper extremity carried upward across the head. Immobilization is secured by means of pillows, sand bags, and the compression band of the diaphragm. Suspension of respiration is essential. The size of the film will depend on the extent of the column being examined, but it should not be smaller than the 10- by 12-inch size. Stereoscopic films in this position may be made.

Lateral films are made by placing the patient on the Potter-Bucky diaphragm in the lateral position, with both arms above the head (Fig. 111). Immobilization, suspension of respiration, the size of the film, etc., are the same as for the oblique views. An anode-film distance of 30 or 35 inches is advisable for the oblique and lateral views. If a slightly higher voltage or longer exposure than is required

for the cervical vertebræ be used, a true lateral view of the first thoracic vertebra may be made according to the method devised by Grandy and described above for a lateral view of the cervical vertebræ (Fig. 108).

A method of making exposures of the lower cervical and upper thoracic vertebræ in the lateral horizontal position has been described by Fletcher. A Potter-Bucky diaphragm is used. In order to secure the correct posture, the patient first sits on the side of the table, places the hand of the side to be examined flat against the forehead, and at the same time rotates the shoulders forward as far as possible. Maintaining the hand and shoulders in this position,

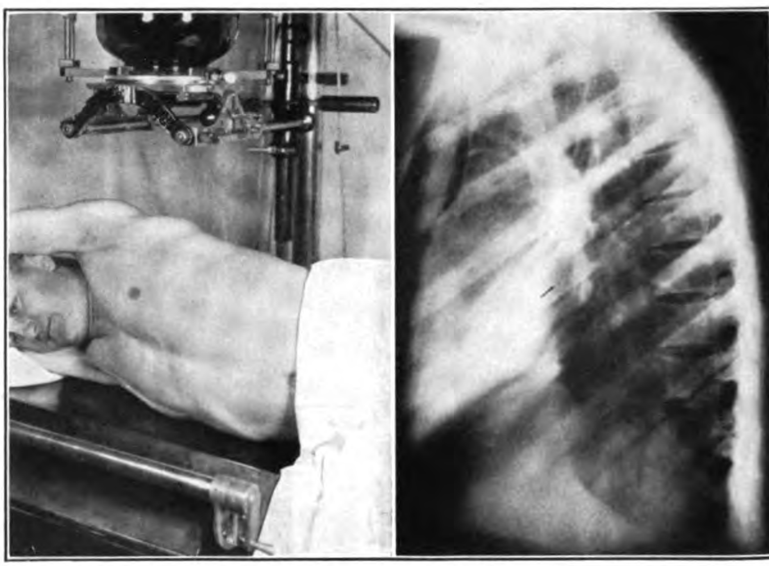

FIG. 111.—Lateral exposure of the thoracic vertebræ. The upper two thoracic vertebræ cannot be shown on this view. A similar position may be used for lateral exposures of the thorax.

the patient is then instructed to lie down on the table in the lateral position. The head is adjusted on pillows or sand bags until the cervical spine is straight and parallel with the diaphragm or table top. The thoracic and lumbar portions of the spine also are straightened by adjusting sand bags or folded sheets under the side between the lower rib margin and the iliac crest. The uppermost upper extremity is extended toward the feet along the lateral side of the body. The compression band is placed across the upper shoulder and traction is applied in a downward direction. When the patient is correctly placed, the lower shoulder is upward as far as possible, the upper shoulder is down as far as it can be pushed, both

shoulders are forward, and the spine is straight and parallel to the diaphragm top.

For the average patient with flexible shoulders the central rays are directed perpendicularly to the film through the upper thoracic vertebræ. If the shoulder be stiff or unusually broad, the tube may be tilted 3 to 5 degrees toward the feet, thus displacing the upper shoulder downward on the film. Films exposed in this way show shadows of the clavicles and scapulæ, and possibly the head of one humerus over those of the spine, but usually the bodies of the lower cervical and upper thoracic vertebræ are well enough pictured for all practical diagnostic purposes. In determining exposure factors, measurements are made between the acromion processes and the voltage is selected accordingly (Fig. 112).

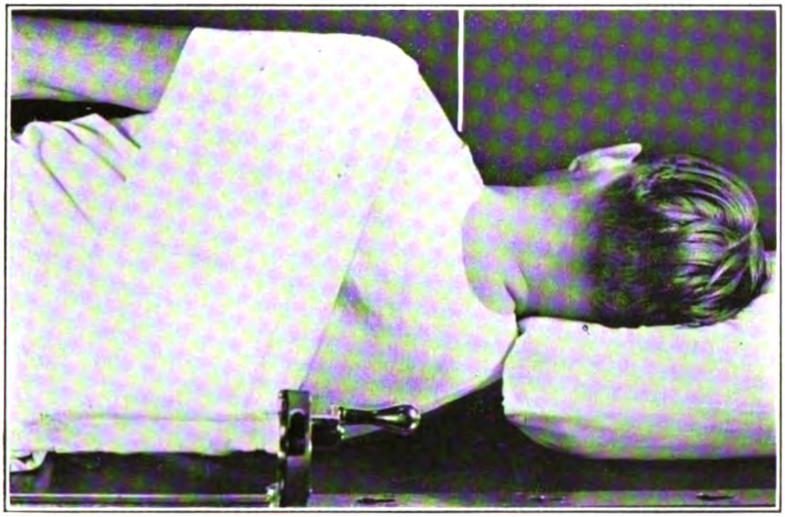

Fig. 112.—Position for an exposure of the cervico-thoracic portion of the spine by the method described by Fletcher. The patient is in a direct lateral position; the hand of the right upper extremity is against the forehead, the left upper extremity is alongside the body with the shoulder forward as much as possible. The entire spine is straightened by placing a pillow between the knees, a folded sheet under the side between the ribs and iliac crest, and pillows under the head. The compression band is fitted tightly across the uppermost shoulder in a position to pull this shoulder downward and forward as much as possible. The rays are directed vertically through the junction of the cervical and thoracic portions of the spine. This is the best position for showing the first, second, and third thoracic vertebræ in a transverse direction. In persons with thick necks or stiff shoulders a downward inclination of the tube for 3 to 5 degrees is advisable.

THE LUMBAR VERTEBRÆ.

Roentgenograms of the lumbar vertebræ should be made stereoscopically in the antero-posterior direction and in the transverse direction, using the Potter-Bucky diaphragm for all exposures.

Because the convexity of the curvature of the lumbar spine is anterior, in antero-posterior views distortion in shape is often quite marked (Fig. 113). If precautions be taken to straighten the spine as much as possible, this will be reduced to a minimum. The shoulders and head should be well supported, the upper extremities flexed across the chest, the compression band of the diaphragm should make firm pressure across the lower ribs and upper part of the abdomen, and the hips and knees should be flexed and supported on pillows, a rolled pad, or a special device placed beneath the knees. An anode-film distance of 30 or 35 inches should be used.

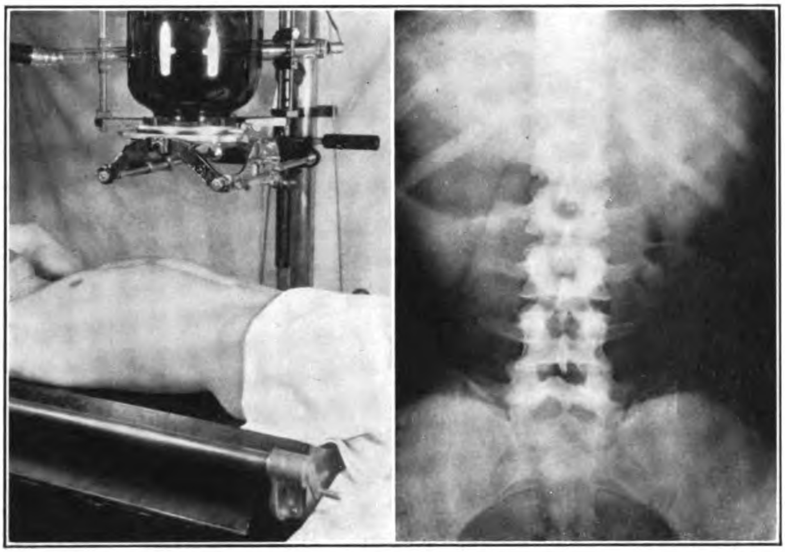

FIG. 113.—Antero-posterior exposure of the lumbar vertebræ. The tube is centered about 1 inch above the umbilicus. For undistorted images of the region of the first lumbar vertebra, the region where more than half of vertebral injuries occur, the tube should be centered halfway between the sternoxiphoid junction and the umbilicus.

Distortion on lateral views also will be present unless the tube is placed so that the rays pass directly through the intervertebral spaces parallel with the margins of the bodies of the vertebræ. In the lateral position the pelvis often is thicker than the trunk through the lumbar region, which causes a lateral bend in the lumbar spine. In making lateral views of the lumbar vertebræ, it is necessary to have the spine nearly straight, with not more than enough curve downward to allow for the natural divergence of the cone of rays from the focal spot of the tube. The patient should be placed in the lateral position on a Potter-Bucky diaphragm or table in which there is a diaphragm. A thick pillow is placed between the knees.

Non-opaque pillows or folded heavy sheets are placed under the side between the lower ribs and the iliac crest and the thickness adjusted until the spine is nearly straight. The compression band is tightened across the hips. Flexing the knees will make the position more comfortable and more easily maintained. An anode-film distance of at least 35 inches should be used (Fig. 114 and A, Fig. 115).

In a complete examination of the lumbar portion of the spine it is necessary to make special oblique views from each side to show the articular processes and the joints between them. Cornwell has examined the angulation of the articular surfaces of the processes in the different portions of the lumbar spine. He found that the angulation of the joints with the median plane varies considerably and was less in the upper than in the lower segments. The angles formed with the median plane from above downward averaged approximately 25, 30, 40, and 45 degrees respectively. These angles suggest that less rotation of the patient in the upper than in the lower portion of the lumbar spine will show more of the joints in profile than if the rotation be uniform.

For oblique views of the lumbar spine Cornwell recommends that the patient be placed supine on a Potter-Bucky diaphragm with the spine in the long axis of the diaphragm. The patient is moved 3 inches to one side and then that side is elevated to an angle of 45 degrees with the plane of the film. This angle may be measured with a 45-degree angle cut from cardboard. The knees are slightly flexed and the hips and shoulders are supported on sand bags or pillows. The tube is located so that the central rays will enter a point 1 centimeter in front of the uppermost anterior superior iliac spine and 3 centimeters above the highest level of the same iliac crest. The opposite side is examined in a like manner.

While it has been generally recommended, the angulation of 45 degrees has not always been found correct. In many instances less angulation is better, the amount of rotation of the patient only being determinable by making more than one exposure.

If there be as much rotary motion on a vertical axis as 22 degrees in the lumbar spine, an alternate method of making oblique views would be to rotate the lower portion of the lumbar region more than the upper. In this procedure the patient is arranged supine on the diaphragm and shifted to one side, the shift being greater in the lower than in the upper part. The shoulders are kept horizontal but the pelvis is elevated until the plane of the back of the sacrum makes an angle of 45 degrees with the top of the diaphragm. The upper part of the lumbar spine and the lower ribs will not be rotated

as much as the lower. If the rotation of these structures then be as much as 25 degrees, the rays will more nearly pass directly through the interarticular spaces. The other details of the exposures are the same as for the 45-degree angle (B, Fig. 115).

In patients with suspected spine injuries particular attention should be paid to the region of the first lumbar and adjacent vertebræ. For this region the position of the tube to the novice will appear unusually high; it should be centered over a point halfway between the umbilicus and sternoxiphoid junction. In the lateral position the tube should be centered about 2 inches above the lower costal margin (Fig. 104).

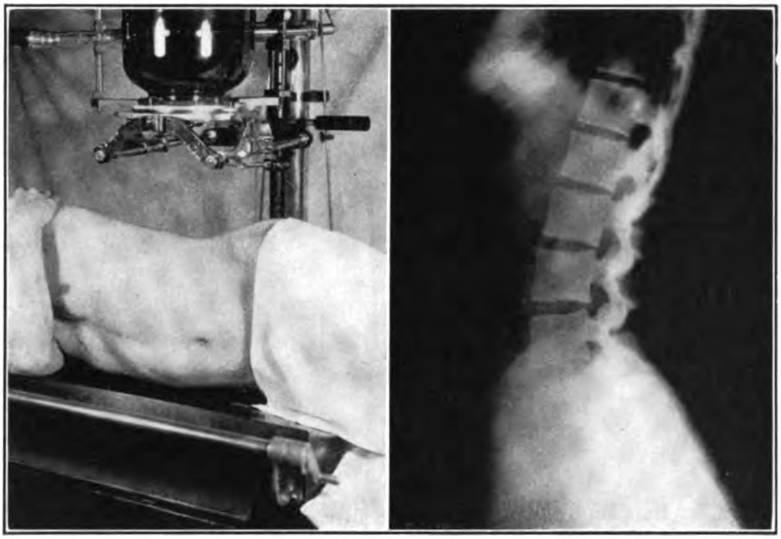

FIG. 114.—Position for a lateral exposure of the lumbar vertebræ. Unless the spine is straightened by a pillow between the knees and a folded sheet under the side between the lower ribs and the iliac crest the tube should be tilted to direct the rays perpendicular to a line extending from the spinous processes of the sacrum to those of the upper lumbar vertebræ.

For views showing all of the lumbar spine the tube should be centered about 1 inch above the umbilicus for the antero-posterior views and over the lower costal margin for transverse views (Figs. 113 and 114). For the lower lumbar and lumbosacral region the tube should be centered on a line connecting the highest points of the iliac crests. This is called the intertubercular line. If the lumbosacral region is to be shown in transverse direction, the tube should be centered over the ilium on a line with the antero-superior iliac spines. In exposing this region in the lateral position the rays must

pass through the hip bones on both sides and through the width of the sacrum, making it one of the longest exposures in all roentgenography (see page 173).

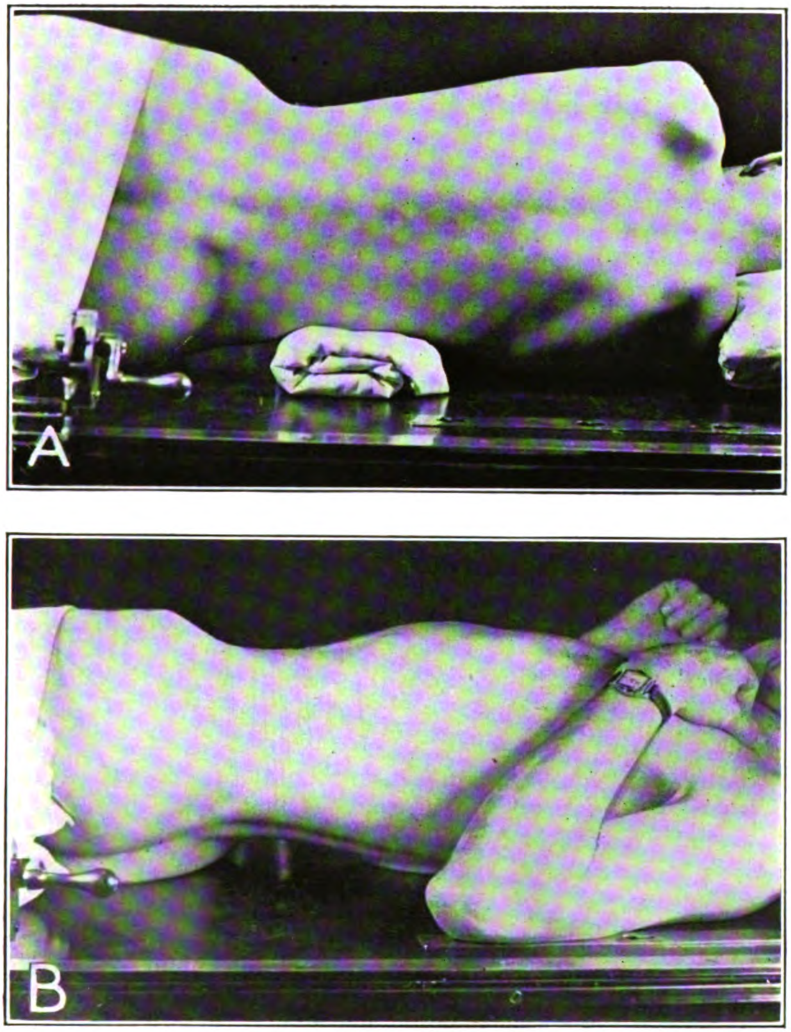

Fig. 115.—A, straightening the spine for lateral exposures of the lumbar and the lumbosacral regions. There is a pillow between the knees, a folded sheet under the side between the ribs and the iliac crest, and a compression band across the pelvis. The head is elevated on pillows; the whole spine straight or curved slightly toward the table in the lumbar portion. B, position for exposure of the articular facets in the lumbar region. The shoulders are against the table and the hips are elevated off the table for 45 degrees. This elevates the lower thoracic and upper lumbar vertebræ for about 25 degrees. Sand bags under the thigh and hip hold the patient in position. An alternate position would be a rotation of the whole spine for 45 degrees.

THE RIBS.

There are twelve ribs on each side. The upper seven of these articulate with the thoracic vertebræ behind, and, by means of their costal cartilages, with the sternum in front. The next three are attached to the vertebræ but their cartilages extend upward to fuse with the cartilage of the rib next above. Thus the eighth unites with the seventh, the ninth with the eighth, etc. The lower two, the floating ribs, have a cartilage-tipped end which terminates in the muscles of the side and back of the abdomen. The twelfth ribs may be rudimentary, even reduced to a small mass attached to the transverse process of the twelfth thoracic vertebra which may be mistaken for a renal stone. A more or less complete cervical rib may be present attached to the seventh cervical vertebra.

As they pass forward around the thorax all the ribs have an inclination downward. This increases from the first to the eighth or ninth and then decreases. The anterior end of the first rib is on the same horizontal level with the posterior end of the fourth. The ribs from the second to the sixth or seventh have their anterior ends on a level with the posterior ends of the fourth rib below.

The costal cartilages increase in length from the first to the seventh, and then decrease, although the costochondral junctions gradually incline away from the midline from the second to the last. From the fourth downward, the cartilages have a distinct inclination upward, which increases from above downward.

The identification of a particular rib often is difficult. It can best be done by identifying a certain rib, then, if necessary, counting to the rib in question. The first rib is not palpable. The second lies on a level with the junction of the manubrium and body of the sternum. At this place there is a slight angulation forward in the sternum—the angle of the sternum—which forms a slight ridge transversely across the bone. The lower border of the pectoralis major muscle reaches to the fifth rib; the highest visible serration of the serratus anterior muscle is attached to the sixth rib; with the upper extremity at the side, the inferior angle of the scapula is over the seventh rib, and the lowest part of the inferior margin of the thorax is said to be formed by the tenth rib.

Fractures of ribs are not uncommon. Fractures of the first and second are rare. The ribs most commonly injured are in the middle, from the fifth to the ninth. The usual cause is direct violence, but compression of the thorax is also a cause. Fractures of the costal cartilages or their separation from the sternum or ribs are becoming more frequent from direct violence against the steering wheel in automobile accidents. The most common site for fractures in ribs is near the midaxillary line.

Roentgenographic examination of the ribs for fractures does not present many difficulties. There are certain precautions, however, that must be observed. If the injury be due to a blow of any sort upon the chest, an examination of the injured region with films large enough to include the entire extent of the ribs under suspicion is all that is required. If the violence has been such that the thorax is compressed either antero-posteriorly or transversely, the ribs on both sides should be examined.

Roentgenograms of the ribs may be made either in the antero-posterior, the postero-anterior, or oblique directions. Since the anterior ends of the ribs are not well shown on antero-posterior

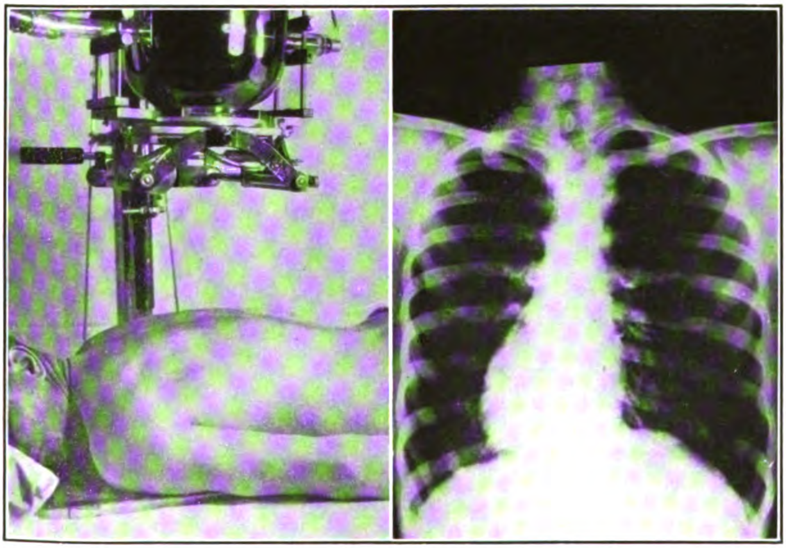

Fig. 116.—Postero-anterior exposure of the ribs. The shoulders are dropped forward so that the images of the scapulæ will not be over those of the ribs.

films, if a single view be made, it should be in the postero-anterior direction (Figs. 116 and 168). The patient may be either in the horizontal or erect position. In either instance the shoulders are rotated forward as far as possible to displace the shadows of the scapulæ off those of the ribs. If an antero-posterior film is to be made, the shoulders may be brought forward by clasping the hands at the back of the head and bringing the elbows together (Fig. 169).

Some fractured ribs in the axillary regions of the thorax may be in the plane of antero-posterior or postero-anterior films and not visible on them. If such be suspected, oblique views should be made. For these the patient is placed with the region of the injury against the cassette, and the rays directed perpendicularly to the film

through whatever aspect of the body the position of the patient requires (Fig. 117). For example, for fractures in the midaxillary region the patient is turned in a semilateral position, and the rays directed toward the film either along the same or the opposite side of the vertebral column.

To show the middle and lower ribs in their entire extent, two films often are necessary. One of these is for the ribs above the level of the diaphragm and the other for those below. The differences in the density to Roentgen-rays of that part of the thorax occupied by the lungs and that part occupied by the liver and other abdominal viscera require a different technique for each part. In making

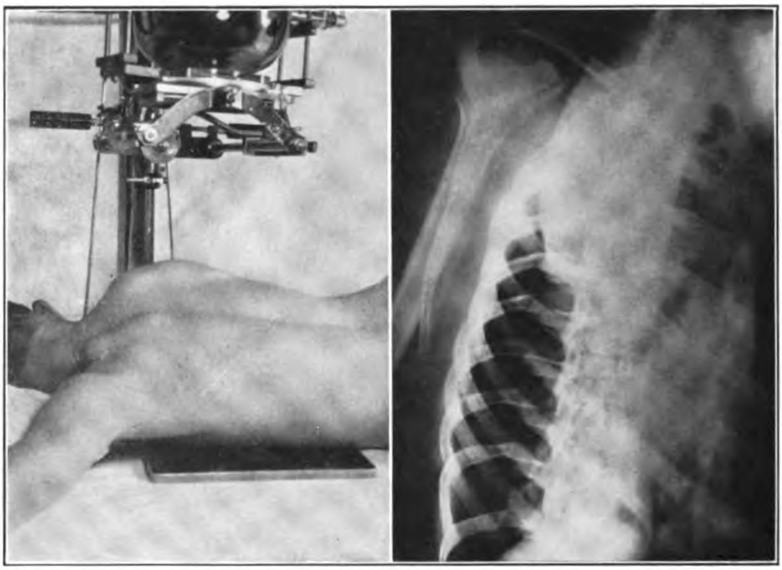

Fig. 117.—Postero-anterior oblique view of the right ribs. By placing the region of the suspected injury on the cassette and making an oblique exposure a film will be obtained that often is more informative than the direct postero-anterior projection.

exposures of ribs lying above the abdominal viscera, the exposure is the same as for the lungs. To include as much of the ribs as possible on such films, they should be made at the fullest inspiration. For exposures of the lower ribs the technique for the abdominal viscera should be used, preferably with a Potter-Bucky diaphragm. To include as much of the ribs as possible on such views, the exposures should be made during complete expiration. Parts of the same ribs will be shown on both films (Fig. 118).

Suspension of respiration, either in full inspiration or expiration, is necessary during all rib exposures. In case of suspected rib injury stereoscopic films will give more information than single films and

are recommended. They may be taken with a vertical stereoscopic plate changer or with a Potter-Bucky diaphragm. If the diaphragm be used, the patient must not move while the film is being changed and the tube shifted between the exposures, and respiration must be suspended at the same point in the respiratory excursion during the exposures.

Unless rather densely calcified, costal cartilages will not be visible on roentgenograms. Occasionally patients will be examined with enough calcium in the cartilages to enable a fracture to be detected. If lime salts be not present, cartilage injury or separation of the

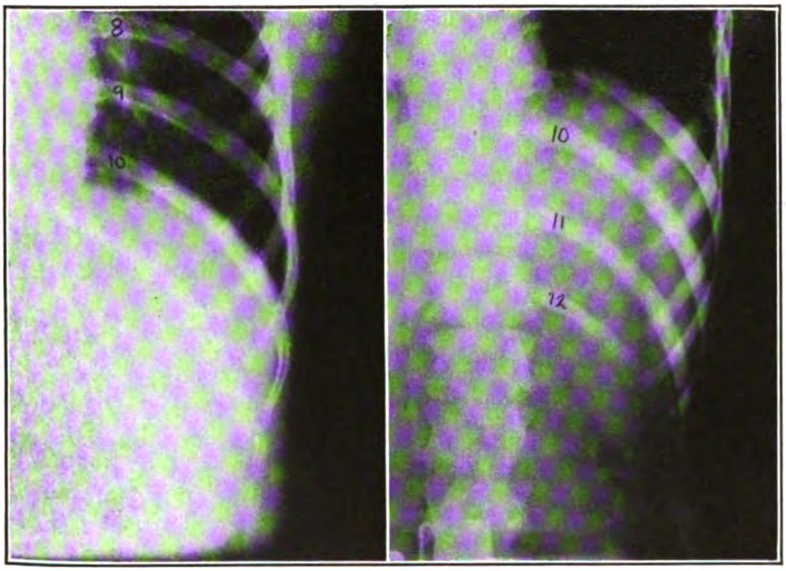

Fig. 118.—Exposure of ribs above and below the diaphragm. Those above the diaphragm are exposed at full inspiration, using factors for the thorax through the lungs; those below the diaphragm are exposed at full expiration, using factors for the abdominal viscera or those for use with a Potter-Bucky diaphragm. Parts of some of the ribs will be clearly shown on both films.

costochondral junction can only be suspected by the abnormal positions of the anterior ends of the ribs.

The size of the films used in making exposures of the ribs depends entirely on the size of the region examined. Probably the 10- by 12-inch size is the smallest that should be used. For all of the ribs on one side of the body the 11- by 14-inch size usually is adequate. If all of the ribs are to be included, the 14- by 17-inch size is required. For small and medium-sized individuals the film may be used lengthwise, but for those that have a large and thick chest it should be turned sidewise.

THE STERNUM.

The sternum, consisting of two bony portions, the manubrium and body, is located in the upper part of the anterior wall of the thorax in the midline of the body. It articulates with the clavicles above, with the cartilages of the upper seven ribs at the sides, and has the xiphoid (ensiform) process or cartilage attached to its lower end. It is cancellous in structure with but little compact bone entering into its formation. Injuries and diseases of the sternum are rare.

Roentgenography of the sternum is rather difficult. Except some of the bones of the face, it is one of the most difficult bones to show satisfactorily on *x*-ray films. This is because of its position directly anterior to the vertebral column and the heart with the roots of the great vessels, both of which are denser than the sternum. Even when taken in an oblique direction so that its image is projected laterally, its shadow is overlaid by the images of the ribs, the heart, and the structures in the lung hilus and is more or less obscured by them.

Because of the great density of the vertebral column, the heart, and the great vessels, it is impossible to make roentgenograms of the sternum in the postero-anterior direction; they can be made in either oblique or in a lateral direction. Pfahler believes that the lateral view is the more valuable. The oblique views should be made stereoscopically and preferably with a Potter-Bucky diaphragm; the lateral view may be made either with or without the diaphragm.

For the oblique view the patient is placed in the prone position with the sternum near the center of the diaphragm, then the left shoulder and left hip are raised on sand bags so that the patient is resting on the right side of the anterior chest wall (Fig. 119). This position will project the image of the sternum on the left of those of the vertebral column and mediastinum. The rotation of the patient to the left should be about one-fourth of a right angle, or $22\frac{1}{2}$ degrees. A similar view may be made with the body rotated in the opposite direction with the left side of the anterior chest wall against the diaphragm.

The lateral view may be made with a Potter-Bucky diaphragm, using an anode-film distance of 35 or 40 inches. The erect position, as recommended by Pfahler, is probably better. The patient sits or stands with the side of the body against a plate-holding device and the rays are directed horizontally through the bone. A small cone and a long anode-film distance (Pfahler uses 40 inches) are necessary. Exposures should be made with respiration stopped during full inspiration.

Runge has described another method of roentgenography of the sternum. The essentials of the method are the use of a non-screen film, the closest possible contact between the film and the front of the chest, the shortest possible anode-film distance, angulation of the tube toward the midline, the exposure of both sides of the sternum on the same film, a relatively long exposure, and, to obliterate by motion the shadows of the posterior ends of the ribs and the lung structures, the continued breathing of the patient during the exposures.

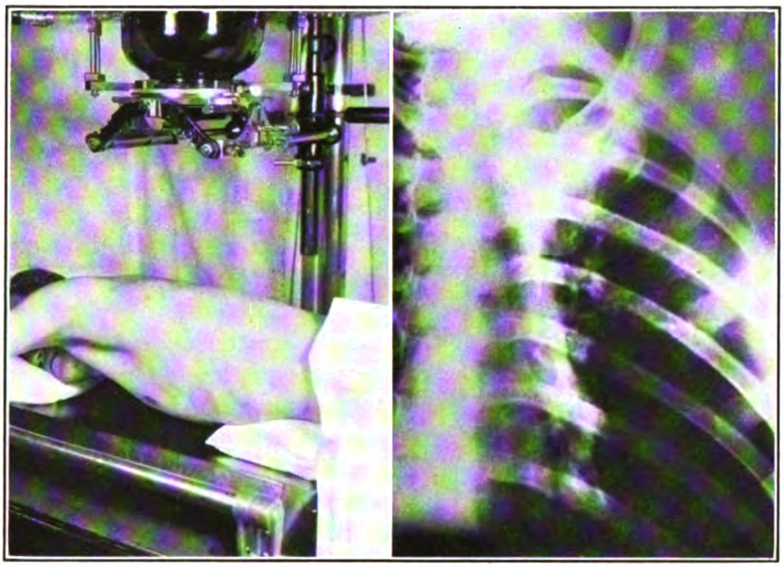

FIG. 119.—Oblique postero-anterior exposure of the sternum with the shadow of the bone displaced to the left of those of the thoracic vertebræ and mediastinum. The left hip and shoulder are elevated on sand bags or pillows.

He uses a light wooden box 4¾ inches high, large enough to hold a 10- by 12-inch film exposure holder in a recess in the top. This is placed on the table, the patient bends forward and places his chest against its top, with the suprasternal notch below the upper edge. The weight is partially supported on the elbows. The tube is angulated toward the midline, a shock-proof tube is used, and the tube is brought down in contact with the patient's back. The amount of angulation varies with the thickness of the chest, being 14 degrees for the thickest (29 cm.) chest and 20 degrees for the thinnest (17 cm.). The tube is centered over the middle of the box and the edges of the filter holder are the same distance from the chest wall. The voltage is varied from 33 peak kilovolts for the thinnest to 73 for the thickest chests. The exposure is 5 milliamperes for

ten seconds, long enough for the patient to take several breaths. While breathing is permitted, the patient must not move during the exposures nor while the tube is shifted to the opposite side for the second exposure.

A 10- by 12-inch film is large enough for any view of the sternum. For the oblique views the central rays should enter the back of the thorax at the level of the spinous process of the fifth thoracic vertebra, a point that can be determined by counting the processes from the vertebra prominens (seventh cervical) downward. For the lateral view the patient should be placed so that the central ray will pass directly transversely through the sternum at a point just below the junction of the manubrium and body.

THE PELVIS.

The pelvis is made up of the sacrum and coccyx behind and the two hip bones laterally and anteriorly. The sacrum is shaped like a triangle with its base upward. The hip bones are irregular in shape. Projecting from the sides of the sacrum lateralward and toward the front are the broad curved alæ of the ilia. Inferiorly these form the upper part of the acetabular cavities. The infero-posterior part of each acetabulum is formed by the strong ischium which extends downward to the tuberosity, then turns forward as the more slender inferior ramus. From the acetabulum the superior ramus of the pubis reaches forward and unites with the inferior ramus to form the body of the pubis, the two bodies articulating at the symphysis pubis in the midline anteriorly. The inferior rami of the pubes extend downward and backward to join with those of the ischia to bound the obturator foramina below.

Fractures of the pelvis, while not common, are not rare injuries, and the increase in automobile accidents is making them more numerous. The pelvis may be fractured in any part by direct violence, or it may be fractured by lateral or antero-posterior compression. Fractures by direct violence depend entirely on the location, kind, and force of the violence. Those from compression are constant in their occurrence. If the compression be antero-posterior, the rami of the pubes and ischium on one or both sides are fractured, sometimes accompanied by a separation of the symphysis pubis. If the force be continued, an injury of the posterior part of the pelvis results from spreading the hip bones apart. This may be a vertical fracture through the sacrum or through the posterior part of the ilium, or it may be a separation of the sacroiliac joint from a rupture of the anterior ligaments.

Lateral compression of the pelvis causes much the same form of

injury. In front the rami of the pubis and ischium give way on one or both sides, or the symphysis is separated. Behind, by forcing the hip bones together, the sacrum or ilium is fractured or the sacroiliac joints give way from a rupture of the posterior ligaments.

Unless associated with a fracture of the pelvis, sacral injuries are rather rare. They are due to direct violence applied to the bone. Dislocations and fractures of the coccyx resulting from falls or other violence are more frequent than injuries of the sacrum. Pain, often attributed to the sacroiliac joints, calls for examinations of this region, which usually includes the lumbosacral joints. While these joints are subject to the same diseases as other joints, it is improbable that dislocations or subluxations without fractures often occur.

Roentgenograms of the pelvis are required for the detection of injuries and diseases of the bones or joints. Most of these are made in the antero-posterior direction. Sometimes postero-anterior films are taken to show the symphysis pubis and the adjacent structures. Oblique antero-posterior films are made for the lumbosacral and sacroiliac regions, the sacrum, and the coccyx. Lateral or transverse films of the lumbosacral joint, the sacrum, and the coccyx are also made. A Potter-Bucky diaphragm or a wafer grid should always be used. Stereoscopic films are preferable to a single film, particularly when the entire pelvis is examined.

Unless the violence suspected of causing a fracture of the pelvis is known to be definitely localized, the entire pelvis should be examined. For an adult this requires 14- by 17-inch films with the long axes of the films across the pelvis. The tube should be centered over a point halfway between the umbilicus and the top of the symphysis pubis (Fig. 120). In making stereoscopic films the tube shift should be in the sagittal plane of the body.

The joint between the fifth lumbar vertebra and the top of the sacrum is oblique in direction from behind downward and forward, and the sacroiliac joints are also oblique in direction, inclining from anterior to posterior and downward. On the usual films of the pelvis these joints are not well shown. With the patient in position as for an antero-posterior film of the lumbar spine, with the knees flexed and a compression band across the lower abdomen, an angulation of the tube toward the head for 15 or 20 degrees and centering just above the pubis will, in most instances, direct the rays through the lumbosacral joint and show it in profile. At the same time the sacroiliac joints will be shown to better advantage. If kept in the line of the grid strips, the tube may be tilted and also shifted in the sagittal plane for stereoscopic films with a Potter-Bucky diaphragm. For these exposures 10- by 12-inch films are adequate (A, Fig. 121).

If an abnormal mobility of the sacroiliac joints be suspected of

being the cause of pain in the back, the range of motion can be determined by a special x-ray examination. With the patient erect, two exposures are made in the postero-anterior direction. For one exposure the weight is supported on the right foot; for the other on the left foot. For each exposure the patient stands on a wood block. The tube is centered through the symphysis pubis. The movement in the symphysis pubis as shown by the difference in the heights of the pubic bones on the two films, reflects the amount of motion in the sacroiliac joints. Eight- by 10-inch films are adequate for these exposures.

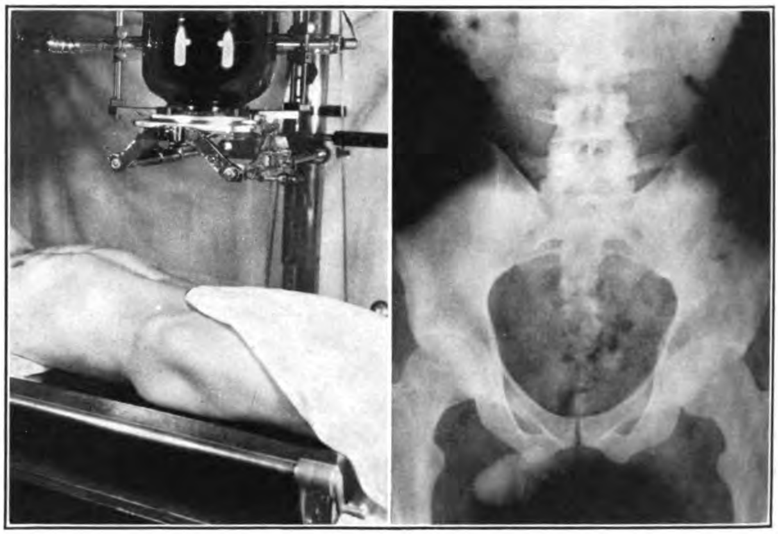

FIG. 120.—Antero-posterior exposure of the pelvis. The tube is centered halfway between the umbilicus and the symphysis pubis.

The coccyx has an anterior inclination and sometimes makes a distinct angle with the sacrum. For special views of the coccyx the lower extremities should be straight; the tube should be centered about 2 inches above the pubis and tilted downward at an angle of 10 degrees. Preparation of the patient to rid the colon and rectum of gas and fecal material is essential. An 8- by 10-inch film is large enough (B, Fig. 121).

Ghormley and Kirklin emphasize the importance of diseases of the lumbosacral joints in lumbosacral backache and sciatic pain, and describe an oblique view to show the facets and joints in profile. The patient is turned at an angle of 32 degrees with the horizontal. To determine the correct angulation, a 10- by 12-inch cardboard angle guide is used. This has a concave border with a line on it from the center of the concave border making an angle of 32 degrees with

the vertical. This fits across the abdomen, the extremities of the concavity resting on the anterior superior iliac spines. The patient is turned until the line is vertical, and the body is held in this position

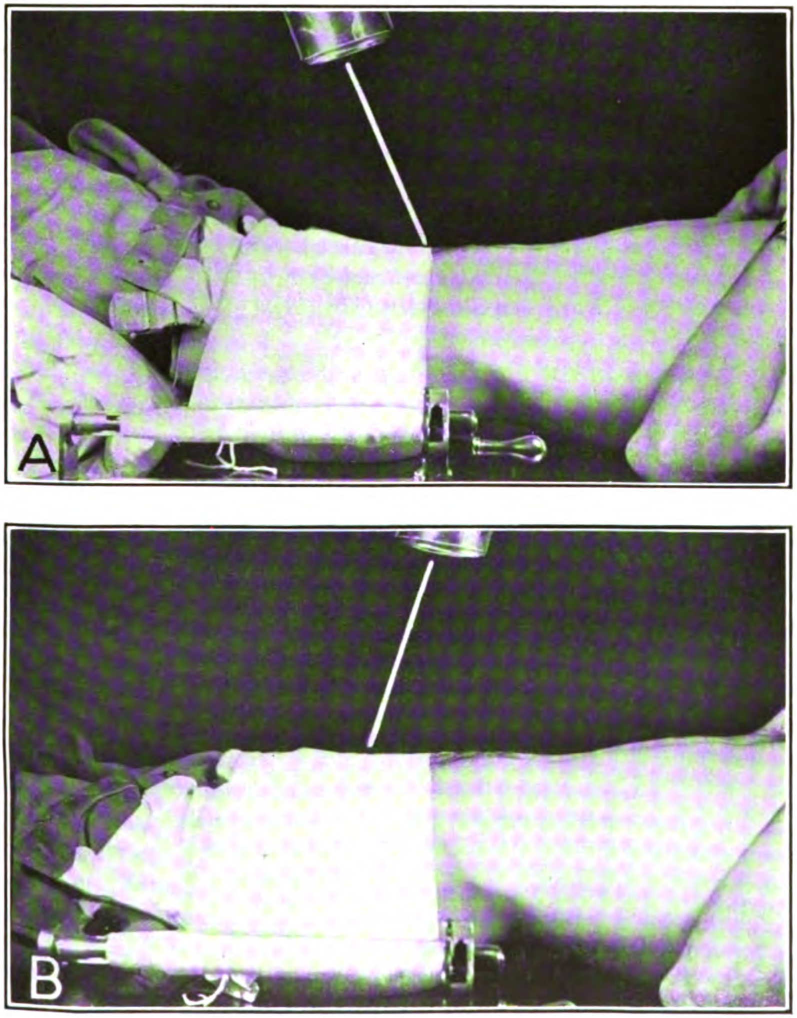

FIG. 121.—A, position for an oblique exposure of the sacrum, sacroiliac, and lumbosacral joints. The knees are placed over a rolled table pad, there is a tight band across the pelvis, the rays are directed upward at an angle of 15 degrees and centered just above the pubis. B, position for an exposure of the coccyx; the patient is supine, the rays are directed downward at an angle of 10 to 15 degrees, and centered a short distance above the pubis.

by means of sand bags and cushions. The rays from a cone of small size are centered over the midpoint of the inguinal (Poupart's) ligament of the elevated side. A Potter-Bucky diaphragm is used. In a majority of instances films so exposed show the facets in profile.

The examination of the lumbosacral joint in the lateral projection is more important than any other. Bowman believes that spondylolisthesis (a displacement of the fifth lumbar vertebra on the sacrum) is a common injury, and emphasizes the importance of making lateral roentgenograms of all patients giving a history of injury or trouble in this region. This joint also is now frequently examined to determine the condition of the intervertebral disk in suspected rupture or protrusion of the disk as a cause of pain in the back and down the sciatic nerves.

For making such an exposure the patient is placed in the true lateral position as described for a lateral view of the lumbar vertebræ (see p. 282). The tube is centered from 1 to 3 inches below the highest point of the iliac crest and about a third of the distance from posterior to anterior along the side of the pelvis. The exposure is usually long, requiring immobilization of the patient with the compression band of the diaphragm. Sometimes exposures of the lumbosacral region are combined with lateral exposures of the lumbar vertebræ and the sacrum. The tube is centered over the lumbosacral joint. A small diaphragm or cone is used for part of the exposure; then the cone or diaphragm is removed, the Potter-Bucky diaphragm reset, and the rest of the exposure made. In this way the lumbosacral region is fully exposed and the lumbar vertebræ are not overexposed.

Lateral films of the coccyx are important for anterior deviations and displacements of this bone. The coccyx is palpable between the prominences of the gluteal regions. The tube is centered directly over the bone.

For films in the prone position, especially to show the symphysis pubis and adjacent structures, the tube is focused over the coccyx and the rays directed perpendicularly. Although the most frequent and extensive injuries of the pelvis are in the anterior part, because of danger of perforating the bladder or tearing the urethra, patients should never be turned to the prone position for postero-anterior views of injuries.

MYELOGRAPHY.

Myelography is the roentgen examination of the spinal canal after visualization is made possible by the injection of some material of greater or less density than the cerebrospinal fluid. At first used in the localization and diagnosis of spinal cord tumors, more recently myelography has been used in the examination of patients with low back and sciatic pain as a result of protrusion or herniation of the nucleus pulposus of the intervertebral disks and of hypertrophy of the ligamenta flava of the spinal column.

Myelography with an opaque contrast medium has been done most often with some preparation of iodized oil. If some of the spinal fluid be removed and replaced with air or oxygen, an examination is made possible because of the diminished density thus produced. Iodized oil gives better visualization than does air or oxygen, but the oil is never completely absorbed. In the course of time some of the oil finds its way to the cerebral subarachnoid space and the rest remains in the lower part of the spinal canal. If a fresh, clear stable oil preparation be used, not more than slight transitory reactions have been observed and there have been no serious aftereffects. The opaque oil, of course, is clearly visible on all roentgenograms made thereafter, and its use is objectionable for that reason. Visualization with air or oxygen is not as satisfactory as with an opaque substance, but this material is completely absorbed in a short time. Perhaps the most acceptable procedure would be first to make an examination using air or oxygen, reserving the dense opaque contrast medium for reëxamination in case the results of of the first are inconclusive or negative.

In opaque contrast myelography the iodized oil is injected into the subarachnoid space of the spinal canal through the lumbar route. Aseptic precautions are observed. A few examiners use 2 cubic centimeters, but 5 cubic centimeters seem to be more generally preferred. The injection may be made on the same day as the examination, or it may be made a day or more before the examination. To allow gravitation of the oil into the lower part of subarachnoid space, before the *x*-ray examination is started the patient should be kept for a time in the erect position.

The examination is both fluoroscopic and roentgenographic. A tilting fluoroscopic table equipped with a head rest and a foot rest is necessary. The patient is placed prone on the table. By tilting the table until the patient is in the Trendelenburg position, the oil is made to flow up the spinal canal. At the same time a fluoroscopic examination is made for signs of blocking of the spinal canal, for filling defects in the oil column, and for other evidences of space-filling lesions. The flow of the oil may be interrupted by moving the patient back to more of a horizontal position.

Such roentgenograms as are indicated by the fluoroscopic findings are exposed. A spot-film device is very satisfactory for this purpose, and Bell has devised a special serial apparatus with which four exposures can be made on one 10- by 12-inch film. If special apparatus is not available, films may be exposed by slipping a cassette under the fluoroscopic screen and closing the shutters of the fluoroscope to a narrow vertical slit. A change-over switch to change from fluoroscopic to roentgenographic voltage and milliamperage

is an aid, but these changes can be made quickly enough by a trained assistant. The film areas that are exposed should be large enough to localize exactly any defects that may be found. If for any reason the first examination is not entirely satisfactory, the examination can be repeated within a reasonable time without repeating the oil injection.

Using air or oxygen as a contrast medium for demonstrating the lower part of the spinal canal, the patient is placed in the lateral position on the *x*-ray table and tilted to the Trendelenburg position at an angle of 30 to 45 degrees. In this position a spinal puncture is done. Spinal fluid is removed and replaced with air or gas in 5 cubic centimeter quantities until no more fluid can be removed. Twenty to 35 cubic centimeters of gas are required to fill the lower part of the spinal canal. The needle is removed and lateral stereoscopic films of the lower part of the spine are taken. The patient is then turned to the supine position and additional stereoscopic films are exposed.

For localizing lesions that cause a complete block in the spinal canal as demonstrated by the Queckenstedt test, 3 to 6 cubic centimeters of cerebrospinal fluid are removed and a like quantity of air is injected into the spinal canal. The patient is placed in the erect position to allow the air to rise in the canal to the level of the obstruction, and films are taken in the erect position.

If a lesion be suspected in the spinal canal above the lumbar portion, the patient is placed in the Trendelenburg position at an angle of 30 to 45 degrees. Spinal fluid is removed and replaced in 5 cubic centimeter quantities by means of cisternal puncture. As much as 65 to 85 cubic centimeters of air are necessary to outline the entire spinal subarachnoid space. When the injection is completed, lateral and antero-posterior stereoscopic films are made.

After air myelography the patient should be kept in a moderate Trendelenburg position (20 to 30 degrees) for six hours. He may then be placed in the horizontal position for twelve hours, and gradually permitted to assume the erect posture over a period of forty-eight hours. If the patient be permitted to be up immediately after the examination, severe headache and other untoward reactions may result.

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CHAPTER XVI.

THE HEAD.

ROENTGENOGRAPHY has an important place in the examination of the head and its various parts for the presence of disease or injury. Examinations that are made are those of the vault and base of the cranium for the detection of fractures, examinations of the bones of the face for fractures, examinations of the sella turcica for abnormalities in size and density of the hypophysis; films of the jaws, especially of the mandible, for fractures; extraoral films of the teeth, and examinations of the temporal bone, mastoid air cells, and nasal accessory or paranasal sinuses for the presence of infection and disease. Occasionally, also, roentgenograms are made in a search for evidences of brain tumors and other conditions causing either mental or nervous disorders.

THE CRANIUM.

By cranium is understood that part of the skull which forms the cavity for the brain, commonly called the cranial cavity. Hence, the cranial bones will include all those of the skull which enter into the formation of the cranial cavity. From a practical standpoint, these may be divided into those which assist in forming the vault of the cranium and those which form the base. From the roentgenographic standpoint, there are four subdivisions of the cranial vault. These include the lateral or temporoparietal region on each side, the frontal region anteriorly, and the occipital region posteriorly.

Roentgenograms of the lateral or temporoparietal regions of the skull show the posterior part of the squamous portion of the frontal bone, the greater wing of the sphenoid, the parietal bone, the squamous and part of the mastoid portions of the temporal bone, and the anterior aspect of the squamous portion of the occipital bone. The frontal region of the skull is made up entirely of the squamous portion of the frontal bone limited inferiorly by the orbital plates of the same bone. The occipital region is composed of that part of the occipital bone lying lateral to and above the foramen magnum. On roentgenograms of this region the foramen magnum is shown near the bottom of the film, the mastoid processes project near the lateral margins, and the lambdoid suture extends across the film like the limbs of an inverted letter V.

The base of the skull is divided into the anterior, middle, and

posterior cranial fossæ. The floor of the anterior fossa is formed by the orbital plates of the frontal bones, the cribriform plate of the ethmoid bone, and the upper surfaces of the lesser wings of the sphenoid. The sharp posterior margin of the lesser wings of the sphenoid bone separates the anterior from the middle cranial fossa. The middle fossa is formed by the greater wings of the sphenoid and the temporal bone. The superior angle of the petrous portion of the temporal separates the middle from the posterior fossa. In the posterior fossa are found the temporal bone behind the superior angle, the base and lateral part, and to a small extent, the squamous part of the occipital bone.

Considered as a whole, the cranium provides a rather dense, rigid, bony case for the brain, the cavity within being an irregular ovoid in shape.

Fractures of the cranium usually are divided into those of the vault and those of the base. Fractures of the vault are described as linear, stellate, etc. They usually are produced by direct violence; either the head is struck by a dense object or the head strikes an unyielding object or surface, such as the ground or pavement. In a very large proportion of instances, fractures of the base of the cranium are extensions of fractures of the vault. Some few may be due to falls or blows on the chin, knees, feet, or buttocks, resulting in fractures in the temporal or occipital regions from violence transmitted through the mandible or vertebral column. Fractures of the vault extending to the base usually reach the base by the shortest route. Those of the frontal region extend to the base in the anterior fossa; those of the parietal region extend to the base in the middle fossa, and those in the occipital bone reach the base in the posterior fossa.

Symptoms resulting from violence applied to the head, such as shock, unconsciousness, delirium, etc., are the general results of the accident and of the injury to the brain. The skull may be extensively injured through the vault, yet there be few symptoms. On the other hand there may be serious shock and severe brain damage and there be no discoverable fracture of any part of the skull. Except in emergency conditions like gunshot injuries and compound depressed fractures, an immediate roentgen examination is not necessary. Even patients with depressed fractures, with fractures complicated by extradural hemorrhage, and with fractures involving the frontal sinuses probably should be treated for shock and brain damage before the cranial injury is directly attached. In only a small percentage of instances does a skull fracture require any direct treatment; and it is doubtful whether a patient ever died of a fractured skull.

Roentgenography of the skull of patients who have received a severe cranial trauma often is very difficult. Chief among the difficulties encountered are immobilization of the part during the exposures and turning the patient to the positions required by the examination. In these maneuvers, especially the attempts to immobilize the head, the patient should not be roughly handled, for there is danger of increasing the trauma to the brain. Immobilization of the head with a double sand bag is permissible, but the application of tightly fitting head clamps probably should be avoided.

FIG. 122.—Position for a lateral exposure of the skull with the patient in the lateral position and the head elevated on a platform. The median plane of the skull is parallel with the cassette and film.

Routine examination of the skull, whether for the detection of fractures or for any other purpose, should include films of the temporoparietal regions from both sides, a film of the occipital bone, a film of the frontal region, and often a film to show the structures of the cranial base. Stereoscopic films materially aid in studying cranial and intracranial changes in form and density, in tracing fractures into the base, in identifying fractures of the inner and outer tables, and in locating depressed fragments. They are preferable to single films and should be taken when possible. Better contrast and detail will be present on films made with a Potter-Bucky diaphragm, but sometimes the condition of the patient precludes its use. A wafer grid is a good substitute for the diaphragm.

For the lateral view without the diaphragm the patient may be placed in the lateral position, the side of the head resting on a cassette elevated from the table on a pile of books, an adjustable platform, or a pile of boards as suggested by Stewart (Fig. 122). The position of the head on the cassette should be such that the median plane (an antero-posterior vertical plane dividing the head into two equal lateral parts) is parallel with the surface of the cassette and a line from the upper teeth through the skull to the

external occipital protuberance is parallel with the inferior margin of the cassette. In this position a line connecting the pupils of the eyes will be perpendicular to the film. By using an adjustable platform or a pile of boards the head may be raised or lowered until the correct position is obtained. The tube should be centered just in front of the pinna of the ear and level with its upper attachment; a cone or diaphragm just large enough to include the necessary film area should be used; the head should be immobilized with a double sand bag and respiration should be suspended during the exposures.

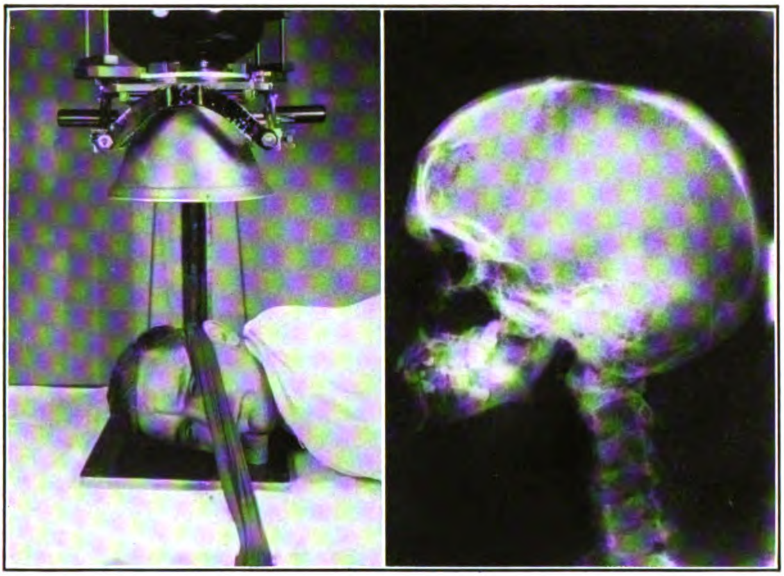

FIG. 123.—Lateral exposure of the skull with the patient prone. The chin is elevated on a large cork to maintain the median plane of the head parallel with the cassette. This position is preferable for comatose patients and refractory children. Except that a smaller cone and a smaller film may be used, this position and the one in Fig. 122 are suitable for exposures of the sella turcica.

If a patient be unconscious and a lateral body position be difficult to maintain, or if a Potter-Bucky diaphragm is to be used, films in the prone position with the head sideways may be made. The arm of the side being examined is placed along the trunk and the opposite shoulder is elevated on a sand bag or pillow. The chin is supported on a bandage roll, a large cork, a folded towel, or other non-radio-opaque material which holds the head in the lateral position (Fig. 123). The median plane of the head should be parallel with the film and the interpupillary line perpendicular to it. Other details of the exposure are like those given in the preceding paragraph.

Occasionally the condition of the patient is such that even turning

to the prone position is inadvisable. The only examination then permissible is one made with the cassette on its end at the side of the patient's head with the rays directed horizontally. Films exposed in this manner are frequently unsatisfactory, but they are the best that can be secured (A, Fig. 127).

A complete examination of the cranium includes a separate film of the occipital region. Only the upper part of the occipital bone is shown on direct antero-posterior films. The lower portion is obscured by superimposed shadows of the orbits, the nasal cavities, and the petrous portions of the temporal bones. A view of the

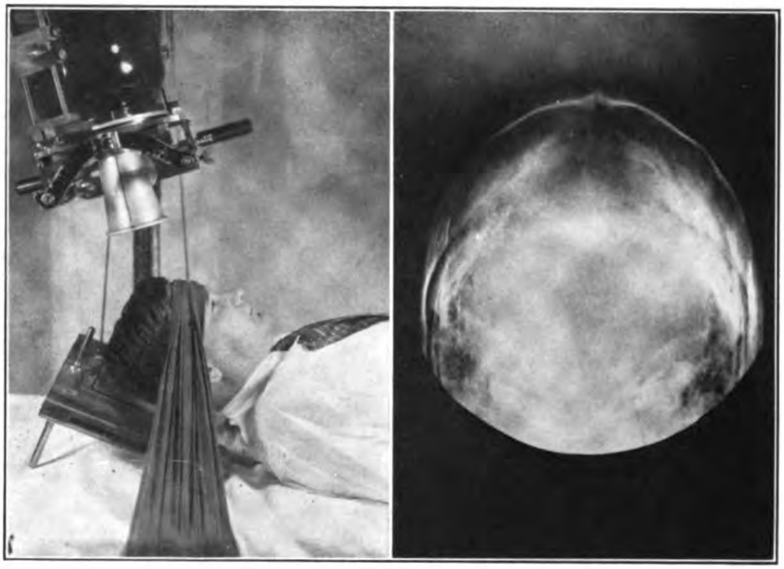

FIG. 124.—Oblique antero-posterior exposure of the occipital region. The combined angles formed by the elevation of the top of the cassette and the tilt of the tube make an angle of 40 degrees. The tube is centered just above and between the frontal eminences.

occipital region must, therefore, be made obliquely downward and backward. The angulation necessary is from 30 to 45 degrees. This may be secured entirely by tilting the tube; or partly by tilting the tube and partly by elevating one end of the cassette or one end of a Potter-Bucky diaphragm. Stewart recommends the use of a 25-degree angle block and a 15-degree tilt of the tube, making a total angle of 40 degrees. A Potter-Bucky diaphragm may be similarly elevated at one end. The same result will be obtained if the patient be kept horizontal, as on a horizontal diaphragm, and the tube tilted for 40 to 45 degrees.

With any method of securing the oblique direction of the rays,

the head is placed with the median plane perpendicular to and over the long axis of the cassette and with the chin depressed onto the chest. The external occipital protuberance should be above the center of the cassette. The central ray is directed into the skull in the median plane and just between and behind the frontal eminences. The head should be immobilized and respiration suspended during the exposure. Without a Potter-Bucky diaphragm a cone or diaphragm of appropriate size is a necessity, and one is also helpful when a Potter-Bucky diaphragm is used (Fig. 124).

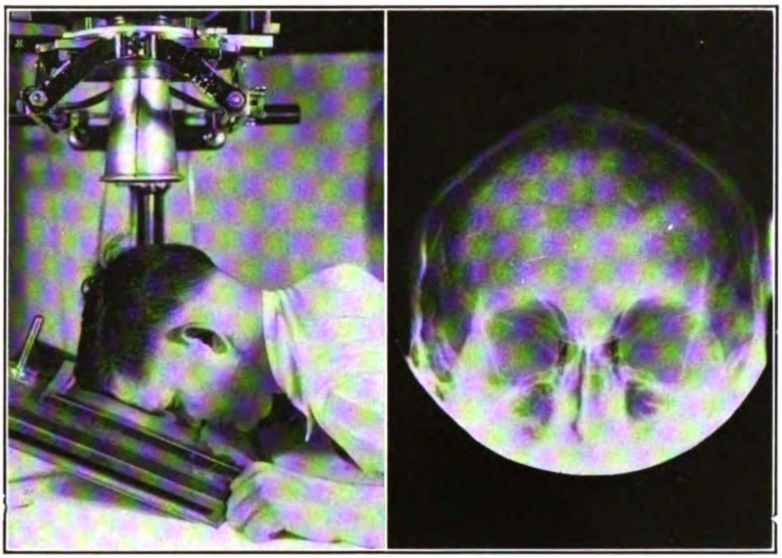

FIG. 125.—Oblique postero-anterior view of the frontal region. The angulation of the cassette and film is 25 degrees, the tube is centered between the parietal eminences.

A prone position of the patient is necessary for satisfactory examination of the frontal region. The cassette should be elevated on an inclined plane or angle block with an inclination of 20 to 25 degrees. The forehead and nose are pressed against the cassette with the glabella near its center. The central rays are directed so that they enter between the parietal eminences and emerge at the root of the nose (Fig. 125). The other details of such exposures are the same as those for other films of the skull. A Potter-Bucky diaphragm may be elevated to the same angle. When a horizontal diaphragm is used, the tube should be tilted 20 to 25 degrees toward the patient's feet.

The posture required for a view of the frontal region of the skull is such that often it cannot be maintained when dealing with comatose or delirious patients. There may be danger of additional

brain injury in attempting to hold the head in the proper position long enough to make an exposure. It then is advisable to attempt an exposure with the tube under the table and the cassette held against the forehead, or the patient may be turned to the lateral position, the cassette held on its side against the patient's forehead, and the rays directed horizontally through the head from behind. Should such measures be impossible or fail, it may be necessary to omit this view (B and C, Fig. 127).

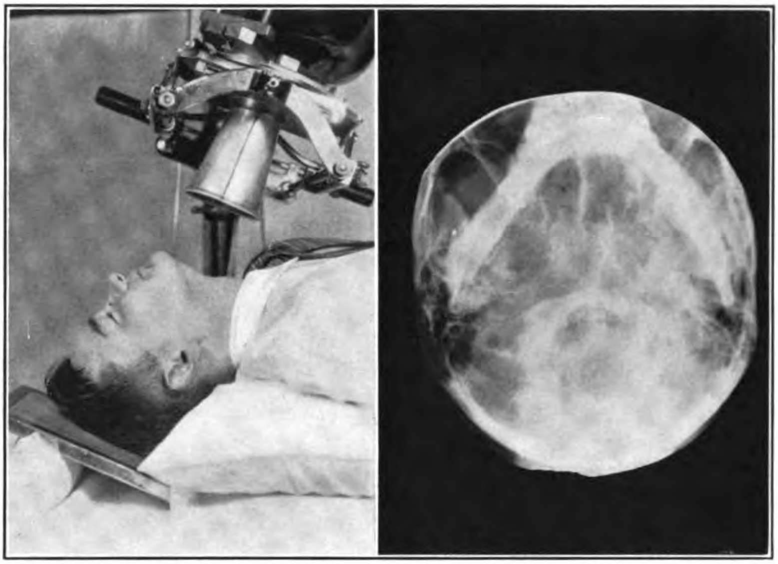

FIG. 126.—Infero-superior exposure of the base of the skull. A line from the external auditory meatus to the lateral canthus of the eye is parallel with the cassette and film; the tube is centered over a point halfway between the larynx and the symphysis of the mandible, the rays being directed perpendicularly to the cassette. This view is the same as that described by Bowen for a film of the sphenoidal sinuses.

A view of the skull that is useful in determining the extent of injuries is one that is taken in the infero-superior direction as described by Bowen for the examination of the sphenoidal sinuses. This often is called the submento-vertex position. This view shows the outline of the mandible and the structures in the base of the skull. It is useful in detecting displacements in fractures of the mandible and zygomatic arches, for determining the size and condition of the sphenoidal sinuses, and for examining the base of the skull. Like other views of the skull, this one may be made without a Potter-Bucky diaphragm, with a diaphragm tilted at one end, or with a horizontal diaphragm. In any case the patient's trunk and shoulders are elevated on a folded table pad, on pillows, or on thick sand bags, and the neck is extended until the head hangs down-

ward as far as it will go. The head is adjusted until a line from the lateral canthus of the eye to the external auditory meatus is parallel with the film. The head may extend off the end of the table with the vertex against the cassette on an adjustable table or stool. The tube is centered over a point halfway between the mid-larynx and the symphysis of the mandible (Fig. 128). Immobilization and suspension of respiration are necessary.

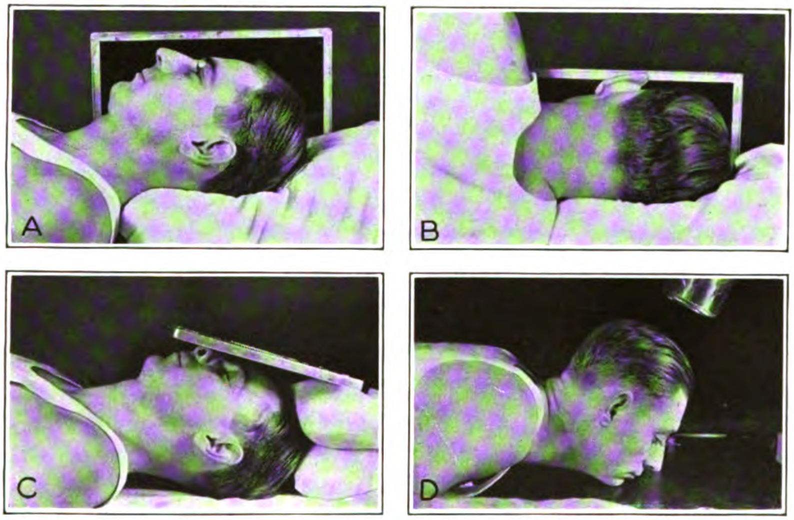

FIG. 127.—A, position for lateral exposure of the cranium with the patient supine. The head is supported by a non-opaque pillow. The *x*-ray film is placed vertically alongside the head, and the rays directed horizontally. B, position for a film of the frontal region with the patient in the lateral position; there is a non-opaque pillow under the head. The film is vertical, and the rays directed horizontally. C, position for a film of the frontal region with the patient supine, the film over the forehead supported by sand bags, and the rays directed vertically from beneath the table top. D, position for vertex-submental exposure of the cranium to show the cranial base, the petrous portions of the temporal bones, and the sphenoid sinuses. The chin is elevated as much as possible and rests on top of the Potter-Bucky diaphragm. By angling the tube toward the feet, the central rays are directed perpendicularly to a plane through the external auditory meati and the floors of the orbits.

For lateral views of the cranium of adults, either single or stereoscopic, films of the 10- by 12-inch size are required. Views of the frontal, occipital, or basal regions of adults or lateral views of children may be taken on 8- by 10-inch films.

VENTRICULOGRAPHY AND ENCEPHALOGRAPHY.

Ventriculography and encephalography are methods of roentgenological examination of the brain and other intracranial structures. In ventriculography the cerebrospinal fluid is removed from

the ventricles of the brain and replaced with air, oxygen, or other gas. If there be no block in the ventricular system, usually almost all of the fluid can be removed and replaced. The ventricles are reached with hollow needles through small trephine openings in the posterior part of the skull.

In encephalography the cerebrospinal fluid is removed from the cranium and spinal canal and replaced with air or other gas by lumbar or cisternal puncture. In this procedure the gas fills the cerebrospinal spaces in the basal region of the cranium, it reaches the subarachnoid space of the cerebral cortex, and it fills the ventricular system to a greater or less extent. The fluid from the ventricles is not as completely removed as it is in ventriculography, but the detection of cortical lesions and diseases is made possible. There are distinct indications and contraindications for each of these procedures. Either requires a high degree of technical skill and neither should be undertaken by a person who has not had special training in this field.

In the *x*-ray examination some examiners first make a fluoroscopic study, followed by the exposure of films. In ventriculography the examination is most often made with the patient in the horizontal position. In this position the gas seeks the highest levels in the ventricular system and whatever fluid that remains gravitates to the lower part. This has prompted the development of special apparatus for this work in which the patient's head is held by a restraining canvas band against an inverted Potter-Bucky diaphragm and the *x*-ray tube is underneath. In these exposures the filled portions of the ventricles will be nearest the films. By using the anode-film distance of 36 inches to reduce distortion, the examination may be made on any horizontal apparatus equipped with a suitable diaphragm. On such exposures the best filled portions of the ventricles will be away from the films.

The *x*-ray examination must be most complete and thorough. Stereoscopic films are exposed from both sides and in the antero-posterior and postero-anterior directions. For the lateral exposures the mid-sagittal plane of the head should be parallel with the films, and in the other exposures there should be no rotation of the head and the chin should be depressed on the thorax to keep the shadows of the frontal sinuses from being projected over those of the ventricles. In addition to the stereoscopic films, to insure an adequate examination of the anterior horns of the lateral ventricles, a lateral film is exposed with the patient in the supine position, with the *x*-ray film vertical, and with the *x*-rays directed horizontally. To insure filling of the fourth ventricle, a similar view is taken with the patient in the prone position.

If the greater portion of the cerebrospinal fluid is not replaced, the difficulty of the *x*-ray examination is increased. Dandy has developed a method of examination in case only enough gas was introduced partially to fill one lateral ventricle. The exposures are made with the film above and the tube underneath. Two lateral exposures are made from each side. To permit the air to fill the anterior and inferior horns of the lateral ventricles, one is made with the forehead rotated slightly toward the film; to fill the posterior horn of the lateral ventricle, one is made with the occiput rotated slightly toward the film. Antero-posterior and postero-anterior films also are taken.

The removal of the cerebrospinal fluid and its replacement in encephalography is done with the patient in the erect position. Lateral, antero-posterior, and postero-anterior stereoscopic films are made with the patient in the same position. For satisfactory results this requires special apparatus, usually a vertical Potter-Bucky diaphragm, or at least an apparatus for holding the films and the head in the vertical position. As in ventriculography, lateral films are also exposed with the patient horizontal, the film vertical, and the rays horizontal, with the patient first supine and then prone, to show the anterior and posterior horns of the lateral ventricles and the fourth ventricle. To prevent distortion the patient's head must be properly positioned for all these exposures.

Cerebrospinal pneumography requires the coöperation of the patient. The suspension of respiration during the exposures and immobility while the second film of each stereoscopic pair is placed are essential. It is chiefly to insure coöperation of the patient that general anesthesia usually is not used during these examinations. The stereoscopic tube shift is horizontal (parallel with the base of the cranium) for the lateral exposures and vertical for the others. The 10- by 12-inch films are required for the lateral and the 8- by 10-inch films for the antero-posterior exposures. For children the next smaller sizes may be used. In the examination of children general anesthesia may be necessary, the exposures must be made as quickly as possible to prevent blurring from unavoidable motion, and sometimes stereoscopy is impossible.

THE BONES OF THE FACE.

Excluding the mandible, which will be considered separately, the only large bones of the face are the maxillæ or upper jaw bones. Because of their exposed position from a practical standpoint the most important of the bones of the face are the nasal and zygomatic bones. The nasal bones are of small size and oblong shape and are

situated at the bridge and root of the nose. The zygomatic bones form the prominences of the cheek. They also form parts of the lateral and inferior margins of the orbits, and articulate posteriorly with the long, slender zygomatic processes of the temporal bones to complete the zygomatic arches.

The nasal bones are probably the most commonly injured of the bones of the face. Fractures of the maxilla from violence to the malar bone driving it into the upper jaw, and fractures of the zygomatic arch, usually the more slender temporal portion, are probably the next most common injuries. While in reality a part of one of the bones of the cranium, roentgenography of the temporal part of the zygomatic arch is similar to that of the bones of the face. Fractures of other bones of the anterior part of the head are uncommon. Such injuries always are due to direct violence. If more deeply placed bones, such as the lacrimal or palate, are injured, it is always as a part of some more extensive injury. Such injuries seldom are recognized, even in the most careful examinations.

The satisfactory roentgenographic delineation of injuries around the nose, cheeks, upper jaws, or orbits is difficult. In direct postero-anterior and lateral views the images of other structures are superimposed, making identification of different parts difficult or impossible.

Films of fractures of the nasal bones may be made in the lateral or supero-inferior directions. For the lateral views the patient may lie with the head elevated and the nose over the center of half of a small cassette. The rays from a dental cone are directed through the nose. The opposite half of the cassette is used for exposure of the other side. Lateral views also may be made on large dental films held alongside the face level with the nose. The Eastman occlusal dental cassette may be used for such exposures. If a dental film be held in the mouth and the rays directed vertically downward along the forehead through the nose on to the film, the inferior portions of the nasal bones will be shown satisfactorily. Care should be taken not to overexpose films of the nose.

The best view of the bones of the face is that made in an oblique direction with the rays directed downward and forward. The images of structures on films made in this manner are very much distorted but they are the best that can be secured. For this exposure the patient is placed prone on the table with the chin resting on the cassette below its middle. The amount of elevation of the head is largely a matter of personal choice. Bowen suggests that the cassette should be placed on an angle block with the nose touching the cassette and the rays directed perpendicularly to the table, passing through the top of the head and centering over the incisor

teeth (Fig. 128). This is somewhat similar to the Waters position for the nasal accessory sinuses. The position suggested by Tittering-

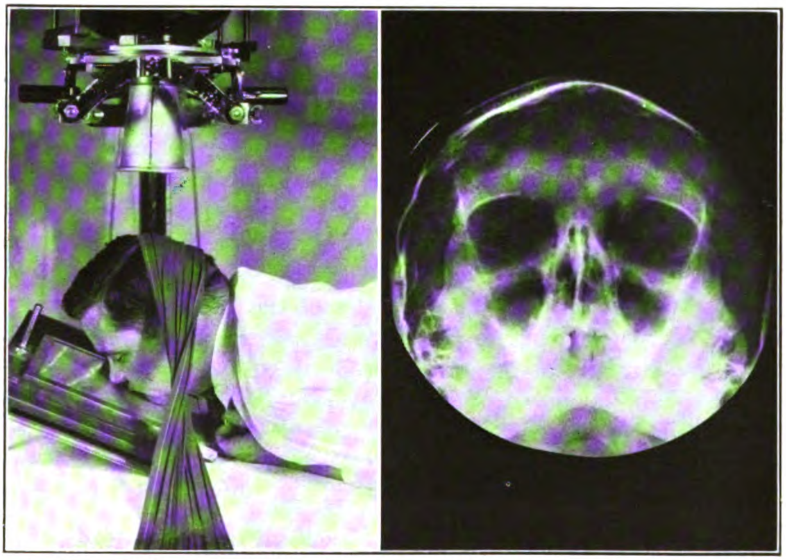

Fig. 128.—Oblique postero-anterior exposure of the bones of the face. The cassette is tilted at an angle of 25 degrees; the chin and nose rest on the cassette; the rays are directed between the parietal eminences.

Fig. 129.—Positions for films of the zygomatic arch. A, in the position described by Titterington, the head is extended, the chin rests on the film or diaphragm, the tube is angulated toward the feet at an angle of 15 degrees and centered so that the rays pass through the zygomatic arch. B, position for an exposure of the zygomatic arch on an occlusal film. The film is out in the cheek as far as possible; the rays are directed downward with a slight medial inclination through the arch onto the film.

ton is slightly different. The cassette is placed on a 23-degree angle block and the nose and chin pressed against it. The rays are directed perpendicularly, the central rays emerging between the malar bones.

For the zygomatic arches the position is the same, but the tube is tilted 15 degrees toward the feet and moved so that the rays pass through the zygoma (A, Fig. 129). The infero-superior view of the base of the cranium as described also will show the zygomatic arches.

A very satisfactory view of the alveolar processes of the maxillæ and the hard palate can be taken with an intraoral film by the method described on p. 358. Without these views fractures of these portions of the upper jaws are sometimes difficult to find. For films of the zygoma the occlusal film may be pushed into the cheek as far as it will go and the rays directed perpendicularly to it alongside the head. They should be angled medially to miss the prominence of the frontal region (B, Fig. 129).

For exposures of films of the bones of the face, immobilization with a double sand bag or head clamps and suspension of respiration are essential. A cone or diaphragm just large enough to cover the area being examined will give better contrast and detail. An 8- by 10-inch film is adequate.

THE SELLA TURCICA.

The sella turcica is the cavity in the upper surface of the body of the sphenoid bone in which is lodged the hypophysis or pituitary body. The size of the sella gives an adequate idea of the size of the hypophysis. Hypophyseal tumors increase the size of the sella, and changes in it and in the anterior and posterior clinoid processes result from long continued increased intracranial pressure due to brain tumors or other causes.

In roentgenography of the sella a true lateral view is necessary. The patient's head must be placed in the lateral position with the median plane of the head exactly parallel with the cassette (Fig. 122). Pfahler has invented a leveling device useful in obtaining the correct position of the head. For the determination of the size of the sella turcica, Pancoast uses an anode-film distance of 36 inches which gives about 10 per cent distortion. For this exposure the central ray enters a point ½ inch above and ½ inch behind the center of a line from the lower margin of the orbit to the middle of the external auditory meatus with the anterior end of the line at the level of the outer margin of the orbit. Satisfactory films show the anterior clinoid processes superimposed, the dorsum sellæ without tilt, and the angles of the mandible superimposed. For the character of the bony walls of the sella and for a study of deformities, he uses a stereoscopic pair of lateral films taken with the Potter-Bucky diaphragm. For the determination of the exact size of the sella, Jewett recommends an anode-film distance of 5 feet, stating that

this will give not more than a 5 per cent increase in size due to distortion.

For these views small films may be used. Immobilization of the head, suspension of respiration, and the use of a small cone are required.

THE MANDIBLE AND DENTAL ARCHES.

The mandible is the largest bone of the face. It consists of a horizontal, curved portion, the body, shaped somewhat like a horseshoe, and open posteriorly. The ends of the body unite with the rami at the angles, the rami extending more or less vertically and dividing at their upper ends into the coronoid and condyloid processes. The condyloid processes articulate with the mandibular fossæ of the temporal bones forming the temporomandibular joints. The upper border of the body of the mandible is known as the alveolar border because it supports the lower teeth, forming the inferior dental arch. Similar borders of the alveolar processes of the upper jaws or maxillæ support the upper teeth, forming the superior dental arch.

Fractures and diseases of the mandible, such as infections and cysts, and a search for the presence and position of unerupted teeth and areas of infection around the teeth, when for any reason intraoral films cannot be taken, are conditions which require roentgenographic examination of the mandible or the dental arches. Fractures of the mandible always are produced by direct violence, usually from blows or falls. Although the bone may be fractured in any part of its extent, the usual site is through the socket of a canine tooth or the mental foramen or just anterior to the angle in the third molar region. Double or multiple fractures are frequent. Large cysts, either single or multiple, and extensive infections are uncommon. Patients with third molar teeth impacted high in the tuberosity of the maxilla or in the angle of the mandible or those whose mouths are sore from infections are sometimes examined by making extraoral films of the teeth.

Roentgenography of the mandible and dental arches is complicated by their horseshoe shape and by the nearness of the base of the skull and the cervical vertebræ. On views in the directly transverse direction the images of the bodies and rami of the mandible and the teeth are superimposed and neither side can positively be identified. For an unobstructed view of any portion of the mandible, recourse must be had to oblique views, directing the central ray from the tube behind the angle of the mandible on one side to show a portion of the opposite side without superimposed shadows. The prone position is perhaps the most satisfactory, but films also can

be taken with the patient in the supine, lateral, or erect positions. On films exposed in the postero-anterior direction the images are more or less obscured by those of the skull and spine.

In an article published in 1919 by authority of the Surgeon-General are described methods of examining the mandible in the prone position. Six positions are included. Two of these are postero-anterior to show the whole bone. The other four are oblique in direction, each intended to define a certain small region.

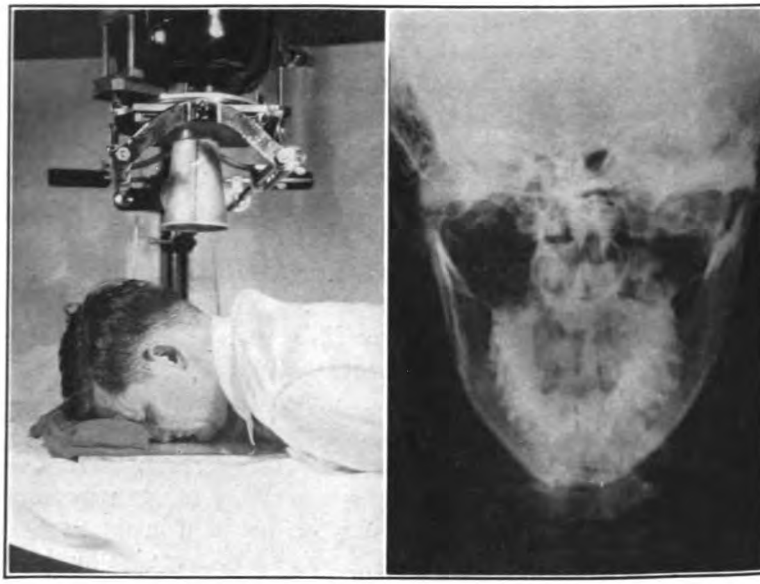

FIG. 130.—Postero-anterior view of the mandible. The forehead rests on a small sand bag; the chin is just off the cassette; a line from the upper border of the external auditory meatus to the lower border of the orbit is perpendicular to the cassette; the tube is centered so that the rays pass halfway between the angles of the mandible.

The postero-anterior views are especially useful in determining lateral displacements in fractures of the mandible. While they include the image of the spine, the entire mandible can be seen distinctly enough for the purpose intended. For the first of these views the patient is placed in the prone position with the median plane in the vertical position and the forehead touching the cassette or resting on a small sand bag. The head is adjusted until Reid's baseline (a line from the upper border of the external auditory meatus to the lower border of the orbit) is also perpendicular to the cassette. The chin will be off the cassette. The tube is focused over the back of the neck with the central rays directed perpendicularly to emerge halfway between the angles of the jaw (Fig. 130). The second postero-anterior view differs from the first in that the

nose and chin are pressed against the cassette and the central rays are directed at an angle of 70 degrees toward the vertex, entering through the back of the neck and emerging through the symphysis. If the patient has been severely injured and particularly if there be injuries elsewhere that prevent turning the patient to the prone position, instead of a postero-anterior view, an antero-posterior exposure should be made. This may be done by placing a film behind the patient's neck, depressing the chin on the chest as much as possible, and directing the rays directly through the face. The anterior part of the mandible will be obscured, but its image will be sufficiently clear to determine the amount of lateral displacement that may be present (A, Fig. 135).

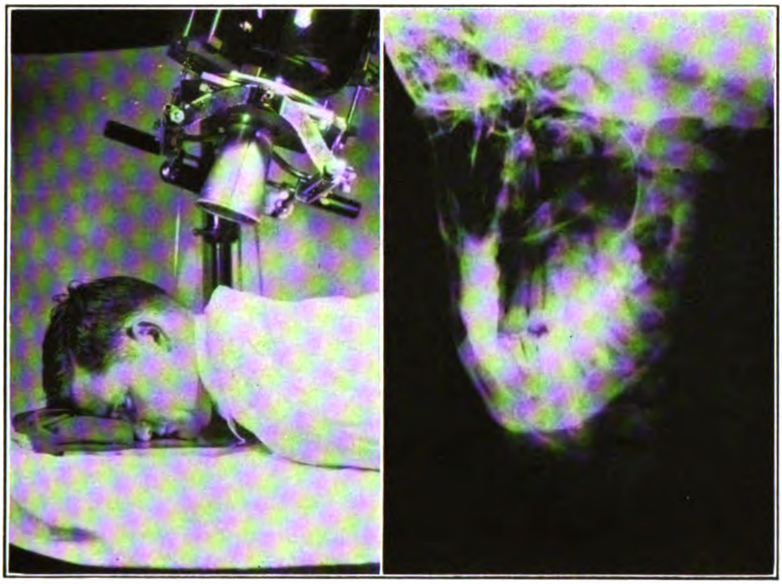

Fig. 131.—First oblique view of the mandible and dental arches to show the region of the symphysis and the canine and incisor teeth. The forehead rests on a small sand bag; the chin just touches the cassette; the head is rotated on a vertical axis so that the body and ramus of the mandible on the side opposite the one being examined (in this case the left) is perpendicular to the film. The tube is tilted toward the top of the head at an angle of 20 degrees, the rays passing between the cervical spine and perpendicular part of the mandible.

Three oblique views are required for a complete examination of the body of the mandible on each side with the corresponding upper and lower teeth; the fourth oblique view is used especially to show the ramus. The first oblique view shows the region of the symphysis of the mandible and the incisor and canine teeth; the second shows the body of the mandible in the region of the bicuspid and anterior molar teeth, and the third shows the angle of the

mandible and the region of the third molar teeth. On each of these the unobscured area will appear on the film between the images of the vertebral column on one side and the opposite body and ramus of the mandible on the other. In a given case, the object of the examination and the region to be examined will determine which of the oblique views should be taken.

For the first oblique view the patient is placed in the prone position with the nose in contact with the cassette and the forehead resting on a small sand bag with the chin touching the cassette. The head is rotated on a vertical axis so that the body and the

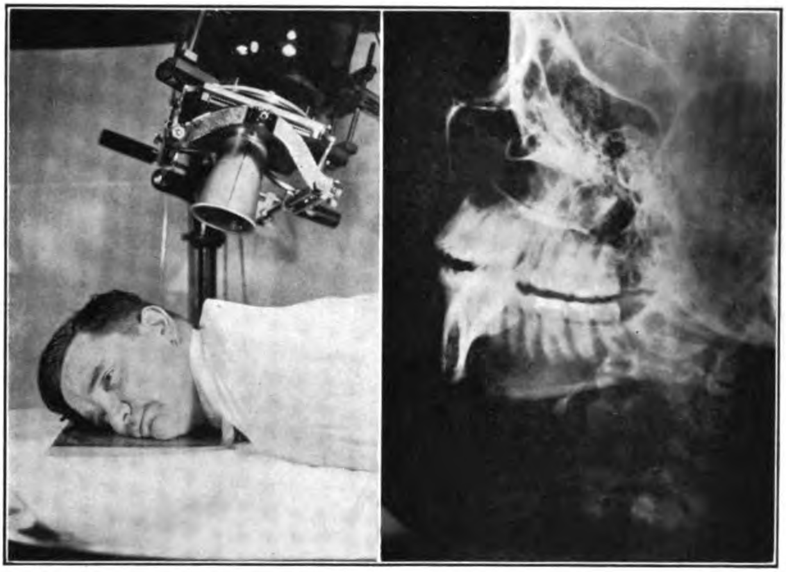

Fig. 132.—Second oblique view of the mandible and dental arches to show the region of the canine, bicuspid, and anterior molar teeth. The side of the mandible is against the cassette; the chin is extended; there is a small sand bag under the occiput; the tube is tilted 10 degrees toward the face and 20 degrees toward the top of the head; the central rays emerge through the middle of the body of the mandible.

ramus of the mandible of the side opposite the one being examined are perpendicular to the surface of the cassette (Fig. 131). The tube is tilted 20 degrees toward the vertex of the head, the rays striking the table top at an angle of 70 degrees and centered between the cervical spine and angle of the mandible to emerge through the symphysis.

For the second oblique view the patient's head is placed with the body of the mandible against the cassette and with its inferior border an inch or more from the margin of the film and parallel to it. The side of the chin must be against the cassette, a position that can be maintained if a small sand bag be placed under the occiput.

The head should be extended and the chin elevated as much as possible. The tube is tilted in two directions forming an angle of 80 degrees with the table top toward the chin and an angle of 70 degrees toward the top of the head (Fig. 132). It is focused so that the central rays will emerge at the middle of the body of the mandible.

For the third oblique view the head is placed with the angle of the jaw against the cassette, the side of the chin being slightly elevated. The tube is tilted as for the second oblique view, the rays emerging at the angle of the mandible (Fig. 133).

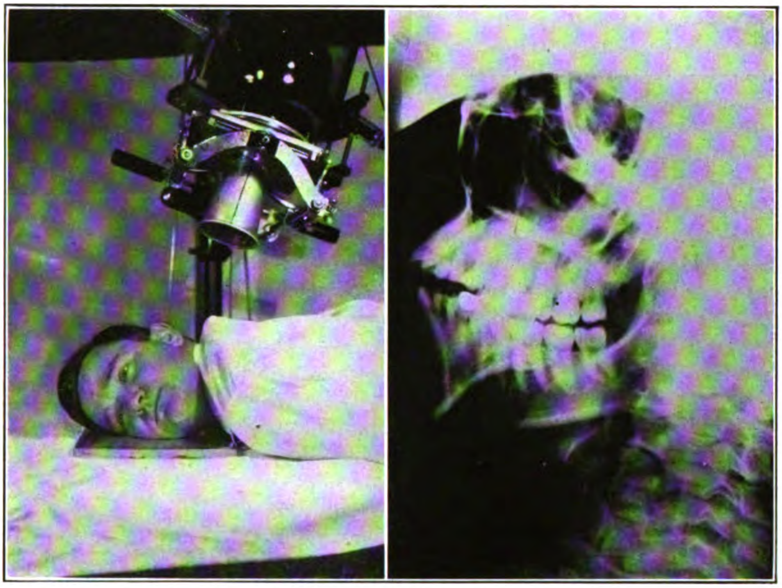

FIG. 133.—Third oblique view of the mandible and dental arches to show the region of the molar teeth. The angle of the mandible is against the cassette; the chin is extended as much as possible; the tube is tilted 10 degrees toward the face and 20 degrees toward the top of the head; the rays emerge through the molar region.

The fourth oblique view is especially useful in showing the ramus of the mandible. For it, the patient is placed in the prone position on the table with the head turned sideways and the median plane parallel with the top of the cassette. The head is extended as far as possible, the chin resting on a bandage roll, a large cork, or other nonradiopaque material. By tilting the tube the rays are directed toward the vertex of the head at an angle of 60 degrees with the table top (Fig. 134). It is adjusted so that the central rays emerge near the center of the ramus of the jaw on the side being examined.

If a patient be encountered who has a flat chest or a rounded dorsal spine, it is advisable to place a large flat sand bag or a folded

pillow under the upper part of the thorax. This will permit the head and neck to hang slightly downward, and will make positioning easier for the oblique views of the mandible.

For oblique films of either side of the mandible with the patient in the lateral position, the inferior edge of the cassette is elevated either on an angle block or a thick sand bag and placed under the patient's chin and against the shoulder. The angle between the cassette and the top of the table should be at least 25 degrees. The central ray is directed perpendicularly to the top of the table and centered just below the uppermost angle of the mandible (B, Fig. 135).

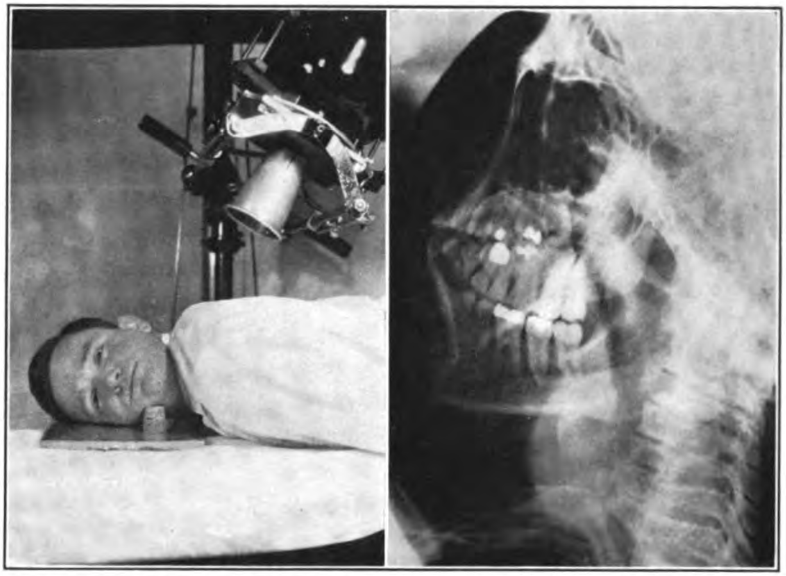

FIG. 134.—Oblique exposure of the ramus of the mandible. The median plane of the head is parallel with the cassette; the chin is extended as much as possible and supported on a large cork; the tube is tilted at an angle of 30 degrees toward the top of the head; the rays emerge through the ramus of the mandible.

With the patient supine the head may be turned sideways with the cassette under the mandible and the median plane of the head parallel with the film. The central ray is directed upward at an angle of 40 degrees and centered to emerge through the body of the mandible that is being examined. It is also possible to keep the chin vertical with the patient supine, to place the film vertically along the side of the face and jaw, and to direct the rays horizontally upward below the angle of the mandible on the opposite side (C and D, Fig. 135).

The mandible is included on submentovertex (p. 306) and on

verticosubmental (p. 307) views of the cranium and sinuses, and a very satisfactory infero-superior view of the anterior part of the bone may be taken on an intraoral occlusal film (p. 360).

To secure immobilization for any of these views of the jaws and teeth, a double sand bag should be placed across the head and respiration suspended during the exposures. A cone just large enough to include all of the area being examined will give the greatest detail and contrast. When the tube is tilted and at a

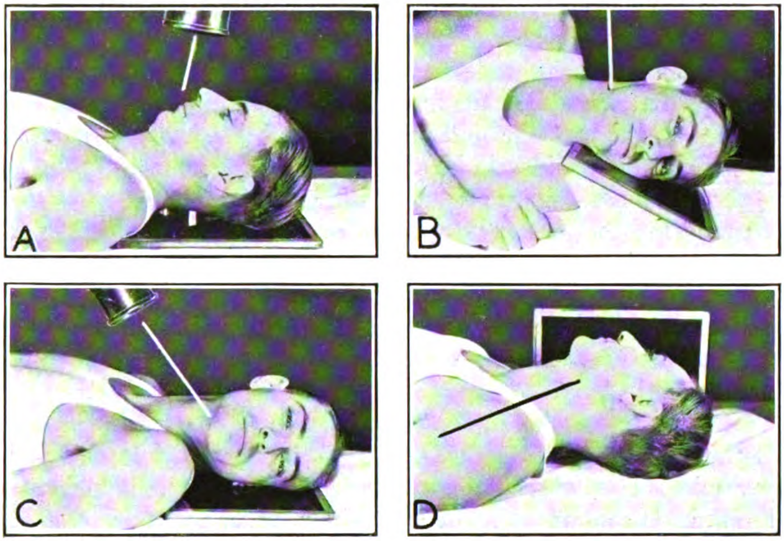

FIG. 135.—A, position for an antero-posterior exposure of the mandible with the patient supine. This exposure is not as satisfactory as a postero-anterior exposure but it will show lateral displacements in fractures. B, position for a film of the mandible with the patient in the lateral position. The cassette is elevated on a sand bag and the patient's head hangs downward. The rays are centered just below the angle of the mandible. C, position for an exposure of the mandible with the patient supine, the head turned to the side, and the rays directed obliquely upward and forward. The rays are centered below the angle of the mandible; the angulation is about 40 degrees. D, position for oblique exposure from below upward through the mandible with the patient in the supine position and the film vertical along the side of the face. The rays are horizontal, angulated upward at an angle of 45 degrees and centered just below the angle of the mandible.

distance of 25 inches or more, it often is difficult accurately to focus it so that the rays will be properly directed. This may be done more easily if the filter be removed from beneath the tube and the circle of illumination from the filament used as an aid in centering the tube. The filter should, of course, be replaced before the exposure is made. Small films may be used for these exposures. By careful posing, similar views of both sides of the mandible may be made on one $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film divided transversely.

THE TEMPORAL BONE.

The temporal bone is located in the middle of the lateral part of the base of the skull. It is composed of four parts: the squamous, mastoid, petrous, and tympanic.

The squamous part is flat and thin. It projects upward from the rest of the bone and assists in forming the temporoparietal region of the skull. It often is the location of fissured or linear fractures that may or may not continue into the external auditory meatus. The slender zygomatic process extends anteriorly, assisting in the formation of the zygomatic arch.

The mastoid part projects inferiorly. It usually is pneumatic in structure, containing the mastoid air cells which are continuous with the cavity of the middle ear through the mastoid antrum. Occasionally mastoids will be encountered of the infantile or diploic type that do not contain air, or one will be found that has undergone a complete sclerosis from chronic infection. The mastoid cells are of different dimensions. Usually smaller cells are found around the antrum and projecting forward into the root of the zygomatic arch, with larger cells along the posterior border and around the tip of the process. Occasionally the cells will project into the squamous portion of the bone.

The petrous portion of the temporal bone is located in the base of the skull between the middle and posterior cranial fossæ. It is pyramidal in shape, projecting medially, forward, and slightly upward. It contains the middle and inner parts of the ear. It may be partially pneumatic in structure, containing air cells.

The tympanic part is the least important portion of the temporal bone. It is located inferiorly, forming a part of the external auditory meatus and the mandibular fossa.

Roentgenographic examinations of the temporal bone frequently are required. Acute and chronic infections in the mastoid and petrous parts of the bone, fractures of the squamous, mastoid, and petrous portions, and tumors of the auditory nerve are the conditions requiring such examinations. Of these, infections of the mastoid cells is by far the most frequent. Roentgenograms, if properly made and correctly interpreted, are a great help to the otologist in detecting the presence, extent, and type of infection of the mastoid cells.

Roentgenography of the temporal bone is complicated by the bilateral symmetry of the two bones in the skull and by the complex structure of each individual bone. Because of the bilateral symmetry, views in the directly lateral direction cannot be made. The parts of the bone are not in the same general planes; views showing

one part to best advantage will give distorted images of the other divisions. To obtain satisfactory views, more than one position must be used and recourse must be had to views taken in an obliquely lateral or other oblique direction. For the mastoid cells and the squamous part the obliquely lateral projections are preferable. The petrous part or pyramid is shown to best advantage by oblique antero-posterior or postero-anterior projections. For the simultaneous exposure of both bones the antero-posterior, postero-anterior, or infero-superior positions are required.

Of the obliquely lateral views especially made to show the mastoid air cells, the mastoid antrum, and the groove for the lateral sinus, the best known in this country is that described by Law. The Schueller projection is somewhat similar. The projections of Granger, Arcelin, Mayer, and Stenvers are oblique antero-posterior or postero-anterior, primarily for the purpose of showing the petrous portion. The mastoid portion also is included. Familiarity with all these positions is not necessary for satisfactory roentgenography of the temporal bones. As suggested by Law, a routine set of films that will give all the information is more satisfactory. One projection to show the mastoid process and one to show the pyramid are necessary for routine examination. In cases of suspected infection deep in the pyramids, use may be made of a comparison film to show the pyramids on the same film.

Views of the temporal bone in the Law position can be made without the use of accessory apparatus. The essentials of the exposure consist in having the median plane of the head parallel with the film and cassette with the pinna of the ear turned forward, tilting the tube toward the face and toward the feet at angles of 15 degrees, and directing the central rays into the head 2 inches above and 2 inches behind the external auditory meatus of the opposite side. In this position the rays pass directly through both the external and internal auditory meati so that they appear as a single dark spot on the film. Around this will be the compact bone forming the wall of the tympanic cavity, behind which will be the cellular portion of the mastoid with the image of the groove for the lateral (sigmoid) sinus extending vertically across its posterior part (Fig. 137).

For exposure of the temporal bone in the Law position, cover one-half of an 8- by 10-inch cassette with sheet lead or heavy lead rubber. Place it on a platform or pile of boards high enough to bring the median plane of the patient's head parallel with the film, with the patient in the lateral posture. Tilt the tube 15 degrees toward the patient's face and 15 degrees toward his feet. Adjust the tube so that the rays from a small cone (4 inches in diameter on

the film is large enough) strike the uncovered portion of the cassette. Without moving the tube or cassette, place the patient's head in position with the mastoid process in the center of the uncovered area with the pinna turned forward. If the upper limit of the pinna be an inch in front of the center of the uncovered portion, the mastoid process will be located properly. Adjust the patient's head until the median plane is parallel with the top of the cassette and a line between the pupils of the eyes is perpendicular to the cassette. Immobilize the head with head clamps or a double sand bag and the

FIG. 136.—Law position for exposures of the mastoid regions. The patient is in the lateral position; the head is elevated on a platform with the median place parallel with the cassette; the tube is tilted 15 degrees toward the face and 15 degrees toward the feet, the central rays entering 2 inches above and 2 inches behind the external auditory meatus to emerge through the opposite mastoid region. The prone position of the body, as shown in Fig. 123, also may be used and is preferable for children.

patient is ready for the exposure (Fig. 136). Respiration should be suspended. When one side has been exposed, the procedure is repeated for the opposite side. Law calls attention to the fact that if the head cannot be placed in the proper position, the deviation of the head must be compensated for in the tilting of the tube.

Children often require examination of the mastoid regions. Should they prove refractory, considerable difficulty will be experienced in obtaining satisfactory films. It probably is better to place these patients in the prone position on the table with the head turned lateralward and with the upper extremity of the side being

examined at the side of the trunk. They can be controlled better in this position than if an attempt be made to elevate the head. The details of the exposure in this position are the same as those given above.

The Schueller position for exposure of the temporal bone is quite similar to the Law position. For this exposure the head is placed in the lateral position with the median plane parallel with the film. The tube is tilted toward the feet, making an angle of 35 degrees with a plane passing through the lower margins of both orbits and the upper limits of the external auditory meati and in a coronal plane passing through both external auditory meati. This position is perhaps the best of the obliquely lateral projections for use with the Potter-Bucky diaphragm.

Several positions have been described for roentgenograms of the temporal bone particularly to show the petrous portion or pyramid. Those of Arcelin (given by Granger) and Stenvers (given by Mayer) are postero-anterior projections and are similar. The Granger position serves the same purpose and is made in the more comfortable antero-posterior projection. In each of these the object is to arrange the head in such a position that the petrous portion of the bone is parallel with the cassette and, by arranging the head and tilting the tube, produce images of the pyramids obscured as little as possible by shadows of other structures.

For the Stenvers position the patient lies prone on the table, with the head turned at an angle of 45 degrees and with the nose, forehead, and malar bone touching the cassette. The tube is tilted in one plane only at an angle of 12 degrees toward the top of the head. The posterior limit of the orbit is at the anterior part of the film area. The central rays enter the opposite side of the head 2½ inches posterior and 2½ inches above the external auditory meatus.

Granger has invented a mastoid localizing apparatus that may be used for making exposures of the temporal bone in the Law position and also in the Arcelin position. It also can be used in making an antero-posterior oblique exposure of the petrous portion of the bone in the Granger position. Because with it one can make similar exposures of both temporal bones and like views of different patients, and can duplicate a previous exposure, this apparatus has been found very useful. By incorporating a cassette-changing tunnel, stereoscopic exposures are possible.

For exposures in the Law position the Granger mastoid localizer consists of a double angle block, a base which fits over an 8- by 10-inch cassette covering one-half of it with lead, and an upright piece into which the patient's nose is placed so that the upper alveolus and glabella are in contact with it. The angle block compensates

for the tilt of the tube, permitting directing of the rays perpendicularly to the top of the table. The piece against which the nose rests is adjustable in height, making it possible to place the head with the median plane exactly parallel with the surface of the cassette. The

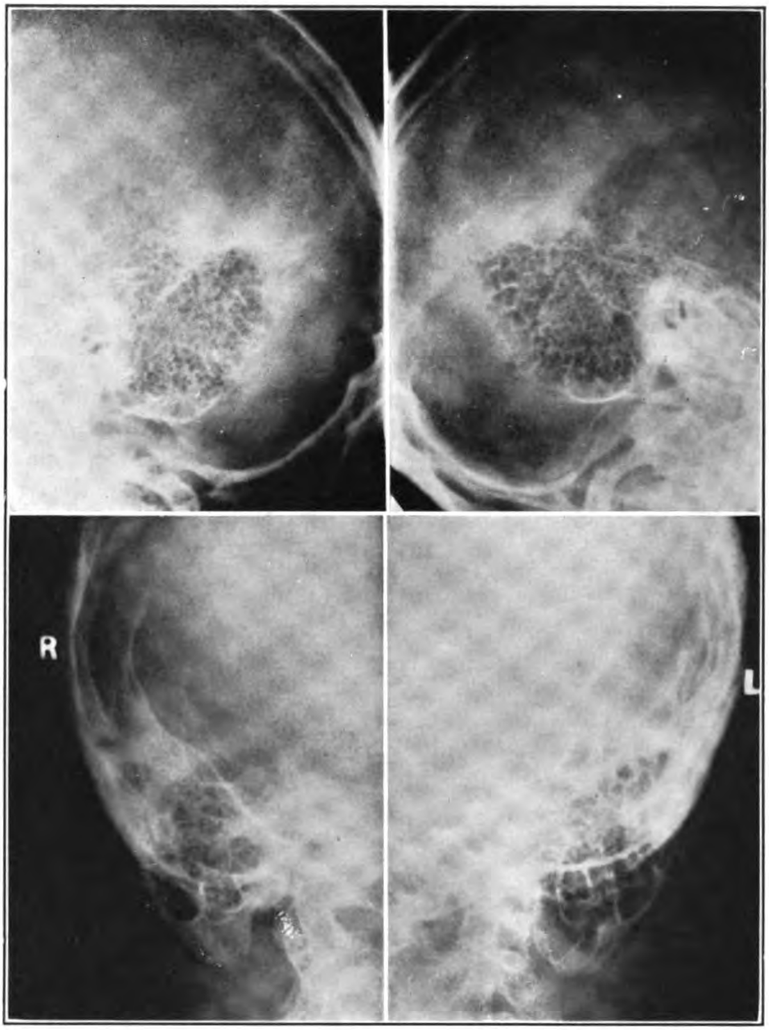

Fig. 137.—Films of the mastoid regions taken in the Law and Granger positions with the aid of a Granger mastoid localizer.

device is constructed so that when it has been adjusted for one side it may be turned around and the same adjustment used for the other side, thus giving similar views of both mastoid regions (Figs. 138 and 139).

For a view of the temporal bone in the Arcelin position the Granger localizer is fitted with two bakelite supports having an angle of 50 degrees. It is placed over a cassette on a 13-degree angle block inclined toward the head. The patient lies prone on the table supporting the body on the elbows. The forehead is placed against the uncovered half of the cassette. The ear and the mastoid are placed in the space between the bakelite supports with the median plane of the head parallel with them. A block of wood 1 inch thick is placed under the upper jaw. The cone of rays is centered about an inch above the mastoid process (Fig. 139). The head should be immobilized with a double sand bag and respiration suspended

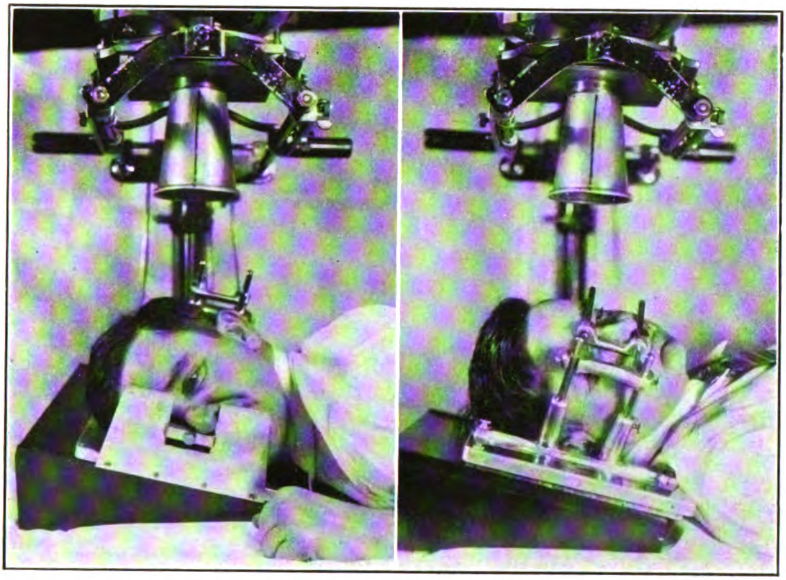

Fig. 138.—The adjustment of the patient for exposures of the mastoid regions in the Law and Granger positions with the use of a Granger mastoid localizer.

during the exposure. After one side has been exposed, the localizer may be reversed and the other side exposed in the same manner.

For an antero-posterior exposure of the temporal bone in the Granger position the mastoid localizer is fitted with adjustable fixation and nose pieces (Fig. 138). The localizer is placed over an 8- by 10-inch cassette on a 17-degree angle block tilted toward the feet of the patient. The patient lies supine with the back of the head against the cassette. The head is turned laterally until the median plane is parallel with the angle supports. The nose piece is adjusted with the septum of the nose and the upper lip against the lower support and the root of the nose against the upper. The

central ray passes through the center of a line connecting the outer canthus of the eye with the upper attachment of the pinna of the ear. When one has been exposed, the localizer may be turned for the exposure of the opposite side.

Sometimes it is necessary to make a comparison of the mastoid or petrous portions of the temporal bones by means of a single exposure. By an exposure similar to that for the occipital bone both mastoid regions may be shown. Instead of the 40-degree angulation of the tube toward the feet of the patient, an angle of 30 degrees should be used (see page 304 and Fig. 124). A comparison view of the petrous portions of the bones is shown on the submento-vertex position for the base of the skull (page 306 and Fig. 126). The petrous portions of the temporal bones may be projected into the orbits by making an antero-posterior exposure with the patient supine and a plane extending through the lower parts of both orbits and the upper parts of both external auditory meati perpendicular to the cassette. The central ray enters the median plane of the head at the place where it bisects the plane given above.

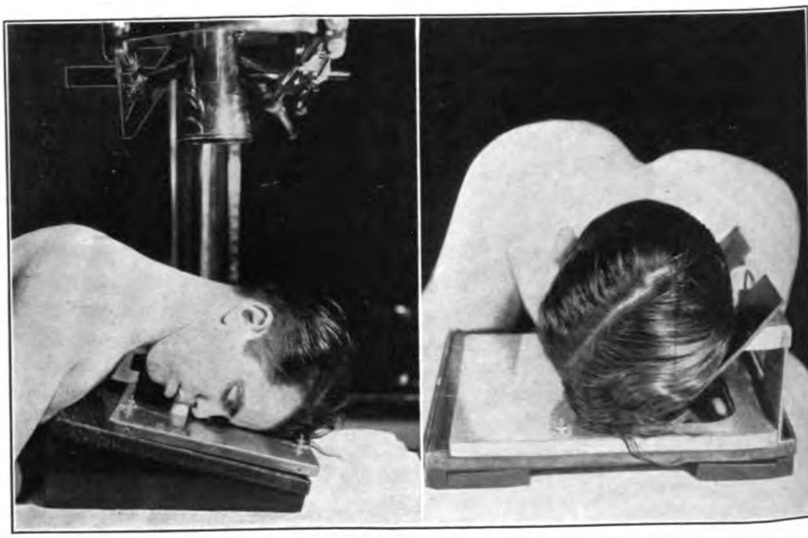

FIG. 139.—The position of the patient for films of the petrous portion of the temporal bone in the Arcelin position, using a Granger localizer.

In making roentgenograms of the mastoid regions, the greatest care should be exercised to be certain that the identifying numbers and letters R and L, designating the two sides on the film, are correctly placed. Since a large part of the interpretation of the films is based on a comparison of the appearance of the images of the two sides, care also should be taken to use identically the same exposure

factors, giving two images of exactly the same roentgenographic density.

By using a cassette-changing tunnel for changing the cassettes, either with or without the use of an angle block or mastoid localizer, stereoscopic films of both mastoids can be made on two 8- by 10-inch films. For exposures in the Law or Schueller positions the tube shift should be transverse. The tube is first centered as for the single exposure. It is then shifted one-half the distance in one direction and tilted at such an angle (usually 3 to 4 degrees) that the cone covers the same film area. After the first exposure has been made, the tube is shifted the full distance in the opposite direction and tilted to cover the same area for the second exposure. For stereoscopic exposures of the temporal bones in the Stenvers, Arcelin, or Granger positions the tube shift is across the petrous portion of the bone, first toward the top of the head and then toward the feet.

THE NASAL ACCESSORY SINUSES.

From the bones in which they are located, the nasal accessory or paranasal sinuses are called the maxillary, frontal, ethmoidal, and sphenoidal sinuses.

The maxillary sinuses, the largest of all, are two in number, located one in each upper jaw just beneath the cheeks. They are pyramidal in shape, with each of their three dimensions measuring more than 1 inch. They are separated by plates of bone from the cheeks in front, the nasal cavities medially, the orbits above, the upper teeth and mouth below, and the pterygopalatine fossæ and pterygoid processes posteriorly. While they are of different sizes in different persons, they seldom vary much in size in the same individual. They communicate by one or more openings with the middle meatus of the nose. They are more often infected than any of the nasal sinuses.

The frontal sinuses are located in the frontal bone just above and between the orbits and above the root of the nose. They are more variable in size and extent than any of the others. Either one or both may be entirely absent or only represented by a small pocket in the bone. Occasionally they are very large, extending entirely across the orbits, high into the squamous part of the frontal bone, and horizontally backward in the orbital plates of the bone. The average dimensions are about 1 inch horizontally and transversely and slightly more vertically. They are rarely of equal size in the same person, the septum between them being deflected to one side. More often the right is the larger. The frontal sinuses are related to the forehead anteriorly, the orbits inferiorly, and the cranial

cavity posteriorly. Each communicates by a narrow canal with the middle meatus of the nose.

The sphenoidal sinuses are two in number, located in the body of the sphenoid bone. Their average dimensions are from $\frac{3}{4}$ to $\frac{7}{8}$ inch. They are separated by a septum which may be in the midline or displaced to one side. Because of this, one sinus may be larger than the other. Occasionally one is entirely absent. The sphenoidal sinuses are related to the base of the brain, the internal carotid arteries, the cavernous sinuses, the optic chiasma, and other important structures. Each communicates by a small opening with the upper posterior part of the nasal cavity.

The ethmoidal sinuses are the smallest of the series. They are in two sets, one in each lateral mass or labyrinth of the ethmoid bone. These portions of this bone extend downward from the cribriform plate between the orbits laterally and the nasal cavities medially. The ethmoidal cells are variable in number and in size. They are usually small, with thin walls, and from three to fourteen in number on each side. The cellular portions of the ethmoid bone in the same person are only occasionally of unequal extent. Those cells in the anterior portions of the ethmoidal labyrinth open into the middle meatus of the nose and are spoken of as the anterior cells. Those in the posterior part open into the superior meatus of the nose and are called the posterior ethmoidal cells. These two groups are not separated by a distinct septum.

The nasal accessory sinuses often are infected, causing nasal discharge, fever, headache, eye disorders, asthma, chronic cough, and other forms of illness. They are placed within the bones of the skull, are of variable size and irregular extent, making their examination difficult. Any method of investigating the condition of these sinuses, therefore, is of distinct value. Probably the best direct method of examination is by roentgenography. Skillfully made and wisely interpreted roentgenograms are of inestimable value in seeking for infection in these spaces.

There are two chief difficulties in making roentgenograms of the nasal accessory sinuses. Because of their position within the skull, especially the posterior ethmoidal and sphenoidal, and the consequent impossibility of placing them close to the film, their images are always more or less distorted. The second difficulty lies in the fact that it is impossible to make films of the skull without projecting on to them images of all parts of the skull through which the rays pass. Thus, if the shadows of the petrous portions of the temporal bone or the floor of the posterior cranial fossæ be placed across those of any of the sinuses, the shadows of the latter will be obscured.

To overcome these two difficulties, numerous methods of making

films of the sinuses have been devised. Lateral and oblique views, postero-anterior views at different angles, infero-superior and supero-inferior projections, and intraoral films have been used. Postero-anterior views, which permit of comparison of the same region on opposite sides of the skull, are probably the best. To secure images of all the sinuses unobscured by the petrous portions of the temporal bones or other structures and with distortion reduced to a minimum, more than one film is necessary. Of the postero-anterior projections that have been described, those of Waters and Waldron, Caldwell, and Granger are the best known.

For a complete routine roentgenographic examination of the nasal accessory sinuses Law recommends a film in the nose-chin or Waters-Waldron position, a film in the nose-forehead or Caldwell position, a pair of stereoscopic lateral films, and a pair of stereoscopic vertex-mental films. Granger uses two postero-anterior films, one corresponding closely to one made in the Waters-Waldron position, and the other in a special position that he devised. Granger does not employ a lateral view except one taken at an anode-film distance of 6 feet for determining the size of the sphenoidal sinuses, the presence of adventitious septa, and for measuring the distance from the nasal spine to the anterior wall of the sphenoid sinus.

In the Waters-Waldron position films are exposed in such a way that the shadows of the petrous portions of the temporal bones are projected below those of the maxillary sinuses. It is particularly useful in examining the frontal, ethmoidal, and maxillary sinuses. The rays are directed from above and behind downward and forward in an oblique postero-anterior direction. The images will therefore appear as oblique postero-anterior projections. The anterior ethmoidal appear above the posterior ethmoidal cells.

For the exposure of films in the Waters-Waldron position the patient is placed on the table in the prone position with the chin resting on a cassette just below its middle. The median plane of the head must be perpendicular to the film and along its long axis. The tip of the nose must be off the cassette. Waters and Waldron say that for those with a convex-shaped face the nose must be 1 centimeter from the cassette, and for those with a concave-shaped face it should be 1.5 centimeters off the cassette. The rays are directed perpendicularly to the cassette and centered so that the central rays emerge through the nose (Fig. 140). Immobilization by means of head clamps or a double sand bag and suspension of respiration are essential.

The Caldwell position gives almost a true postero-anterior projection of the nasal sinuses. On films made in this position the shadows of the petrous portions of the temporal bones fall two-

thirds across the lower parts of the orbits and one-third across the upper parts of the maxillary sinuses. Such films are particularly good for the frontal sinuses and show the inferior portions of the maxillary sinuses. The shadows of the anterior and posterior ethmoidal and sphenoidal sinuses are more or less superimposed.

For exposing films of the sinuses in the Caldwell position, the cassette is placed on an inclined plane or angle block having an angle of from 15 to 25 degrees, with the patient's forehead and nose pressed against the cassette with the nose just below its middle.

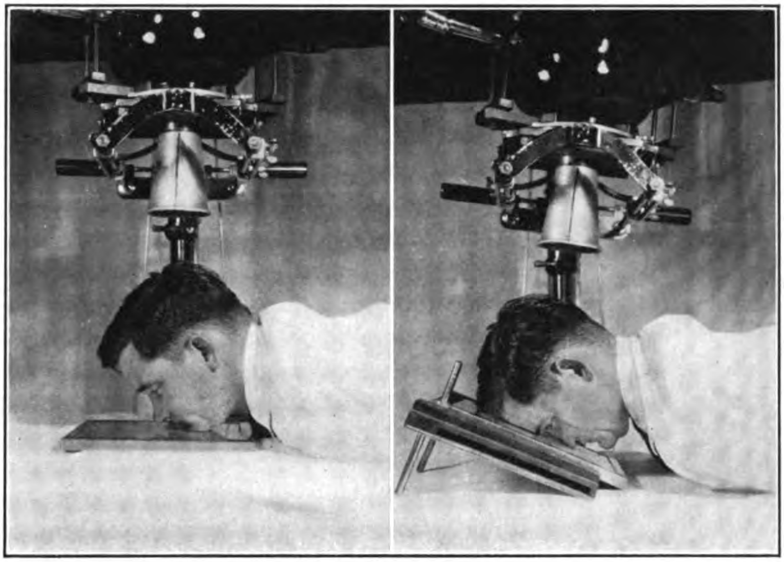

Fig. 140.—At the left, adjustment of the patient for an exposure of a film of the nasal accessory sinuses in the Waters-Waldron position. The chin rests on the cassette; the nose is 1 centimeter off the cassette; the tube is centered so that the central rays emerge through the nose. At the right, the arrangement of the patient for a film of the nasal accessory sinuses in the Caldwell position. The cassette is elevated and the tube tilted so that the central rays form an angle of 23 degrees with a line extending from the external auditory meatus to the glabella and emerge through the root of the nose.

The median plane must be perpendicular to the cassette and along its long axis. The tube is tilted in such a way that the central rays pass through the head forming an angle of 23 degrees with a line connecting the glabella with the external auditory meatus (Fig. 140). To assist in directing the rays, Law has devised an angle of 23 degrees with a long and a short arm. The short arm is 6 inches in length; the long arm has been lengthened and made like a folding ruler. This angle is held at the side of the patient's head with the short arm extending in the line from the external auditory meatus to the glabella or the lateral limit of the eyebrow. The tube is

tilted until the central rays coincide in direction with the long arm. The long arm also is used in measuring the anode-film distance.

The Granger position is designed especially to give information about the sphenoidal sinuses. The head is placed at an angle of 107 degrees with the vertical, or 17 degrees with the horizontal, and the rays directed in an oblique postero-anterior direction from behind forward and upward. The shadows of the petrous portions of the temporal bones fall within those of the orbits. On views made in this position the rays have passed tangentially through the bone forming the floor of the optic grooves in the roof of the sphenoidal sinuses, causing it to appear as a curved line called by Granger the G line (Fig. 143). Information with reference to the sphenoidal sinuses is derived from the appearance of this line and the region immediately below it. Experience has taught those who are familiar with this method to place great confidence in Granger's conclusions concerning the diagnostic significance of films made in this position.

Satisfactory films in the Waters-Waldron and Caldwell positions can be made without the use of a special sinus block or board; but, since the angle must be exact, for films in the Granger position such an accessory apparatus is necessary. The one designed by Granger is very satisfactory. This block utilizes what Granger calls the alveolo-glabellar position. There is a hole in the top of the block in which the patient places his nose, the head resting below the hole on the upper lip, alveolus, and teeth, and above the hole on the glabella. Provision is made for two views, one with the top of the block forming an angle of 23 degrees with the top of the table and the other in the Granger position. The film exposed with the top in the 23-degree angle position (this angle must not be confused with the 23-degree angle used in the Caldwell position) is somewhat similar to one made in the Waters-Waldron position in that the petrous portion of the temporal bones are below the maxillary antra or across their lower portions.

An angle block of the Granger type, utilizing the alveolo-glabellar position, simplifies roentgenography of the nasal sinuses and provides a method of duplicating results difficult to obtain in any other way. A film exposed in the Caldwell position may be used as a check on the one made in the 23-degree position. A simple modification of the Granger block makes provision for this position also and serves as a block for making stereoscopic postero-anterior exposures. In addition to the two positions advocated by Granger, provision is made for fixing the top nearly horizontal, sloping at an angle of only 3 degrees toward the patient's feet. Films exposed with the top at this angle will be in the Caldwell position (Figs. 141 to 143).

In exposing films of the cranial sinuses with a block of this sort, it is placed near one end of the table, and tilted at the desired angle, with the top in the proper position and the cassette in place. The tube stand is fitted with a cone that should not be larger than 2½ inches at the smaller end and 4 inches at the larger. This should be placed accurately over the hole for the patient's nose, and the tube swung up out of the way until the patient's head is in place. The patient lies prone on the table, supporting the chest on the elbows, with his nose in the hole, his head making equal pressure above and below the hole (Figs. 141 to 143). The median plane of the patient's head should be perpendicular to the top of the table and exactly in the long axis of the top of the block. To assist in immobilization, a double sand bag is placed across the head. The anode-film distance is then measured, the tube moved to the proper height, the patient is instructed to hold his breath, and the exposure is made. When one film has been exposed, it is necessary to have the patient sit up while the block is being adjusted and the tube centered for the exposure in the next position. The Granger block is used in the same way.

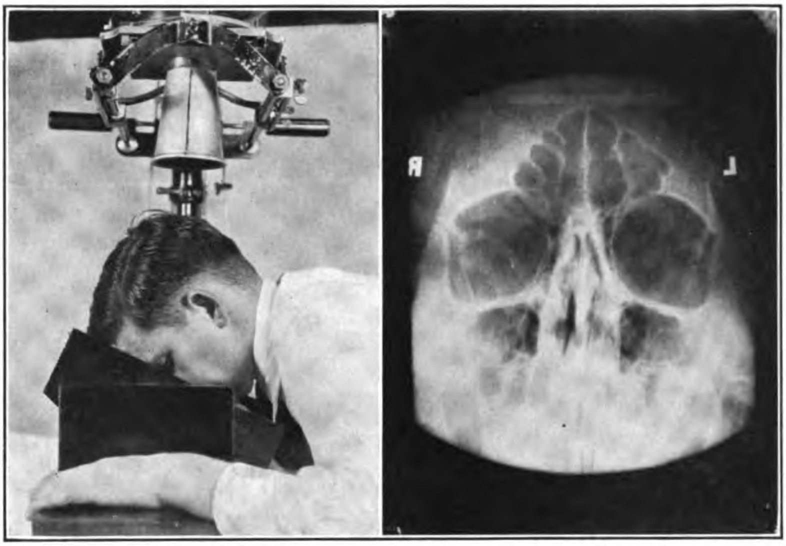

FIG. 141.—Exposure of the nasal accessory sinuses with the modified Granger angle block. The alveolo-glabellar position is utilized; the top of the block forms an angle of 23 degrees with the table. The film is somewhat similar to that obtained in the Waters-Waldron position.

In making stereoscopic films of the sinuses, a cassette-changing tunnel or some other provision for changing the cassettes is necessary. The nose-forehead or Caldwell position is probably best for

stereoscopic exposures, with the nose-chin or Waters position next. The shift of the tube may be either in the longitudinal or transverse direction. The head must be securely immobilized, for the slightest

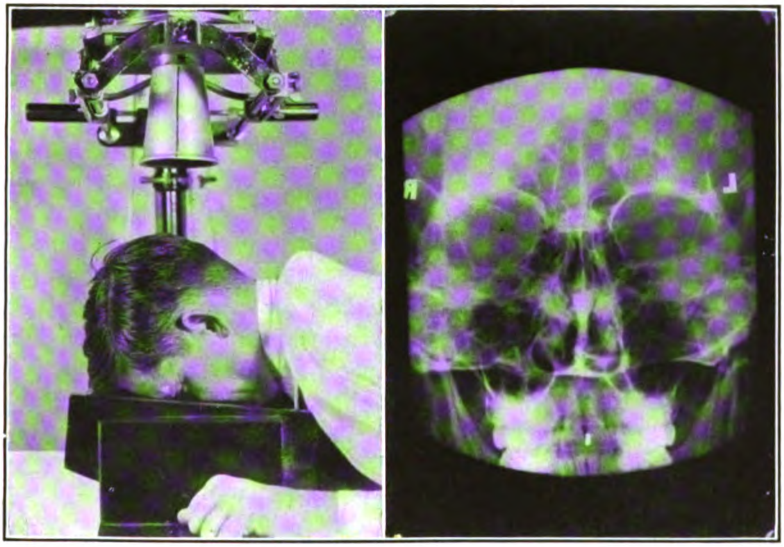

FIG. 142.—Exposure of the nasal accessory sinuses in the Caldwell position with the modified Granger angle block. The alveolo-glabellar position is utilized, the top of the block forming an angle of 3 degrees with the top of the table.

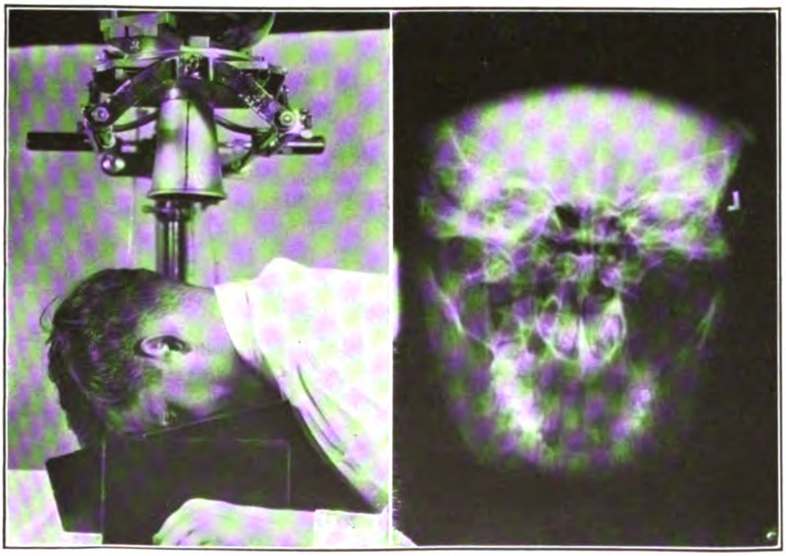

FIG. 143.—Exposure of the nasal accessory sinuses in the Granger position. The alveolo-glabellar position is used, the top of the angle block forming an angle of 17 degrees beyond the horizontal with the top of the table. The central rays from the tube pass just inferior to the external auditory meatus.

change in position between the exposures while the cassettes are being changed will spoil the results.

Films through the sinuses in the lateral direction are valuable for determining the topography of the sinuses. Granger advocates teleoroentgenography of the skull for this purpose. He is convinced that the lateral view is not of value in the diagnosis of pathological conditions within the sinuses. The lateral views do show the depth and height of the frontal sinuses, the thickness of their walls, and the size and depth of the sphenoidal sinuses.

Contrary to the opinion of Granger, Law depends on stereoscopic films of the sinuses for the diagnosis of ethmoidal sinus disease.

For the lateral view the head is placed on the cassette which rests on an elevated support (Fig. 122); for stereoscopic films the support must include a cassette-changing tunnel. The median plane of the head must be exactly parallel with the top of the cassette. Law centers the tube so that the shadows of the malar processes of the maxillæ will be superimposed. For the second exposure the tube is shifted the required distance toward the back of the head and the tube tilted to cover the same film area.

Vertex-mental views of the skull may be made in two ways. In one way the vertex of the head is on the cassette as advocated by Bowen. This has been described on page 306. In the other way the patient lies prone with the chin completely extended on the cassette. The cassette is elevated and placed as nearly as possible in contact with the neck with its lower margin resting on the clavicles. The tube must be tilted toward the patient's feet at such an angle that the central rays pass along a plane extending through points 1 inch in front and 1 inch above the external auditory meati to the angles of the mandible. If the projection be correct, the shadows of the sphenoid sinuses will be within that of the mandible. A film taken in this way also makes a good comparison view of the petrous portions of the temporal bones. For stereoscopic exposures the tube shift should be transverse (D, Fig. 127).

A black border around films of the sinuses improves their appearance and, by increasing contrast, assists in the interpretation. To make this border, the central part of the cassette is covered with a piece of sheet lead of suitable size and shape, an identifying number is placed at the top of the cassette, and the border of the film is exposed to a small quantity of rays.

OPTIC FORAMINA.

One or the other of the optic foramina may be involved in a tumor of the optic nerve, a tumor of the cranial base or brain, or in a fracture. Films showing the size and shape of the foramina and

the surrounding structures may be of distinct value. The optic canals on the average form an angle of 38 degrees with the mid-sagittal plane of the skull, and a similar angle with the base of the skull—the plane extending through the inferior margins of the orbits and the external auditory meati. To picture the foramina to best advantage the rays should be directed as nearly as possible through the canals and the shadows of the foramina projected into the outer parts of the shadows of the orbits. Pfeiffer has designed a special head rest and Camp and Gianturco have made a metal localizer for radiography of the optic foramina.

In making roentgenograms of the optic foramina without the use of accessory apparatus, the patient is placed prone on the table with the orbital margin and malar prominence in contact with the cassette or top of a Potter-Bucky diaphragm. The head is rotated laterally until the mid-sagittal plane makes an angle of 38 degrees with the vertical or 52 degrees with the horizontal. The tube is angled toward the feet, the angulation depending somewhat on the position of the patient's head. If the tip of the nose touches the cassette or diaphragm, the angulation, according to Morgan, should be 12 degrees; if the nose be pressed down until the bridge makes contact, the angulation should be 20 degrees. The rays are centered to enter 2 inches above and anterior to the ear and to emerge through the medial portion of the orbit. The head must be immobilized and respiration suspended during the exposures. For comparison both sides must be examined. The smaller film sizes are adequate for these exposures.

THE TEMPORO-MANDIBULAR JOINT.

Pain in front of the ear and on opening and closing the lower jaw is a symptom that occasionally calls for exposures of the temporo-mandibular articulations. Because of the opacity of the surrounding structures this joint is difficult to examine. An obliquely lateral and an oblique antero-posterior exposure are the most satisfactory.

For the first of these the patient's head is placed in the lateral position on a cassette or Potter-Bucky diaphragm that is inclined 23 degrees toward the feet. The rays are directed perpendicularly and focused with the central rays entering the opposite side of the skull ½ inch anterior and 2½ inches above the external auditory meatus to emerge through the articulation nearer the film. Two exposures are made of each side, one with the mouth closed, the other with it open.

For the second exposure the patient lies in the supine posture with the external occipital protuberance above the center of a film that is inclined 35 degrees toward the patient's feet. The position of the head should be such that the projection of the foramen

magnum will be near the center of the film with the median plane in a vertical position. The chin is depressed on the thorax as much as possible. The central rays should pass along the middle of a plane connecting a point 3 inches above the bridge of the nose with the external auditory meati. With the rays directed perpendicularly to the horizontal, if the central rays do not pass through this plane, the tube should be tilted until the correct projection is obtained.

This film should show the temporo-mandibular joints, the condyles of the mandible and the foramen magnum. It also gives a satisfactory comparison roentgenogram of the petrous portions of the temporal bones.

For these exposures immobilization of the head with a compression band or a double sand bag and suspension of respiration are required. For exposures without a Potter-Bucky diaphragm a small cone must be used. The lateral exposures, two of each articulation, may be made on one 8- by 10-inch film; an 8- by 10-inch film is required for the antero-posterior exposure. Stereoscopic films may be taken by exposing the first film in the position described and shifting the tube toward the top of the head for the second exposure.

WITH A POTTER-BUCKY DIAPHRAGM.

Because of the absorption of scattered rays where large areas are examined, a Potter-Bucky diaphragm or wafer grid can be used to advantage for many exposures of parts of the head. If tilting of the tube to obtain the desired view does not prohibit use of the diaphragm, it is especially useful in those instances where films of the entire skull are exposed. Films of the cranium in all of the four directions, of the sella turcica and bones of the face, and views of the nasal sinuses in the Waters-Waldron and Caldwell or similar positions can be made with a diaphragm. For small portions of the head, as the sella turcica, the mastoid regions, the different exposures of the mandible, and even the nasal sinuses, which permit of the use of a small cone, films without are about as satisfactory as those exposed with one; hence a diaphragm is not generally used for such exposures. In fact, many roentgenologists are convinced that films made with a diaphragm show less soft tissue detail and for that reason object to its use. Many kinds of accessory apparatus, such as sinus and mastoid localizers, cannot be used with a Potter-Bucky diaphragm.

Where available and where the condition of the patient permits, a diaphragm should be used for films of the cranium and face to detect bone injury and for a study of cranial contents. As in all other parts of the body having a complicated structure, stereoscopic are preferable to single films. The patient's head must be placed

against the top of the diaphragm in the required position without the use of a platform or other apparatus that might be used without the diaphragm. With this exception the posing of the patient is the same as that already given. The compression band of the diaphragm serves as an excellent immobilizing device.

Since the separation of the part and film by the grid and top of the diaphragm, especially in examining a large part like the head, considerably increases distortion, a 30- or 35-inch anode-film distance must be used.

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CHAPTER XVII.

THE TEETH.

IN roentgenography of the teeth the first important essential is a knowledge of the appearance and the arrangement of the teeth in the alveolar processes of the jaws. Only the major facts can be given here. For the details standard texts on medical or dental anatomy should be consulted.

There are eight teeth in each half of each jaw. From the center in front, backward, these are named the central and lateral incisor teeth (I, Fig. 144), the canine or cuspid tooth (C), the first and second premolar or bicuspid teeth (P), and the first, second, and third molar teeth (M). Each tooth has a crown which projects

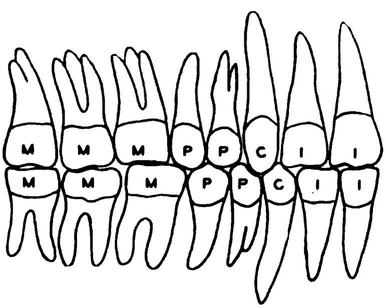

FIG. 144.—The teeth in the right half of the upper dental arch. I, incisor teeth; C, canine tooth; P, premolar or bicuspid teeth; M, molar teeth.

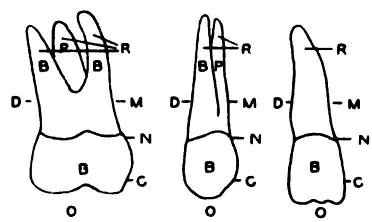

FIG. 145.—An upper incisor, premolar, and molar tooth showing the different parts. The explanation is given in the text.

above the gum (C, Fig. 145), a neck which is surrounded by the gum margin (N), and one or more roots extending into the bone of the jaw (R). The incisor teeth have a chisel-shaped crown with a single conical root. Those in the upper are larger than those in the lower jaw. The crowns of the canine teeth are large and conical. The roots are single and cone-shaped and are the longest of any of the teeth. In cross-section the crowns of the premolar and molar teeth are roughly quadrilateral. The premolars have a flat root which may be divided at the tip. Each of the upper molar teeth has three roots (Fig. 145), one diverging mesially and known as the palatal or lingual root (P), and two on the lateral aspect, nearly parallel with

each other, and known as the buccal (bucca, cheek) roots (B). Each lower molar has two roots, an anterior and a posterior or mesial and distal.

Each tooth has an occlusal aspect (O, Fig. 145)—that which looks toward the opposing tooth in the opposite jaw. While this is of small extent on the canines and incisors, the premolars and molars present distinct, although irregular, occlusal surfaces. That part of the tooth which is toward the midline of the teeth (in dental anatomy the space between the central incisors) is called the mesial surface (M, Fig. 145), and that away from the midline is called the distal surface (D). The surface toward or in contact with the cheek is known as the buccal surface (B), and that toward the tongue or palate is the lingual (lingua, tongue) or palatal surface. The space between two adjoining teeth is known as the proximal space, the surfaces being known as the proximal surfaces.

The alveolar processes of the upper jaws and the alveolar margin of the lower jaw, with the contained teeth, are shaped much like a horseshoe and are sometimes called the alveolar or dental arches (A, Figs. 151 and 153). Because of the greater width of the incisor teeth in the upper jaw, the upper dental arch is more rounded in front and larger than the lower. In different persons there is considerable variation in the size and shape of the dental arches. This is chiefly in the curvature of the arch in front. Some are well rounded and broad, others are narrow and almost pointed, with many intervening variations.

The inner surface of the alveolar process of the upper jaw recedes from the necks of the teeth to merge with the lower surface of the hard palate. This slope is variable in the mouths of different persons and depends on the height to which the palate extends above the teeth. When the palate has a high arch, the inner surface of the alveolar process is more nearly parallel with the teeth than when the arch is low. Variations in palatal contour are illustrated in Fig. 165.

Alveolar abscesses around the apices of the teeth and pyorrheal infections around the necks of the teeth are foci from which infections may spread to more important structures. Such infected areas are so clearly indicated on roentgenograms that roentgenographic examination of the teeth is an indispensable part of a thorough general examination of patients. In excluding infection of the teeth, a complete examination is necessary. While it may be possible to include most infected areas by an examination of all crowned and filled teeth, the spaces from which teeth are missing, and the teeth suspected of pyorrheal infection, a complete examination will show many unsuspected diseased areas.

In making a complete dental examination, the number of films used differs in different laboratories. Eleven films is the minimum. It is impossible to show all the teeth on a fewer number of films, and even with eleven the exposure technique must be exact to include all of the teeth. The eleven films are used: one for each of the four molar regions (Films 1, 6, 7, 11, Fig. 146); one for each canine and premolar region (Films 2, 5, 8, 10); one for the lower incisor teeth (Film 9); and two for the upper incisor teeth (Films 3 and 4).

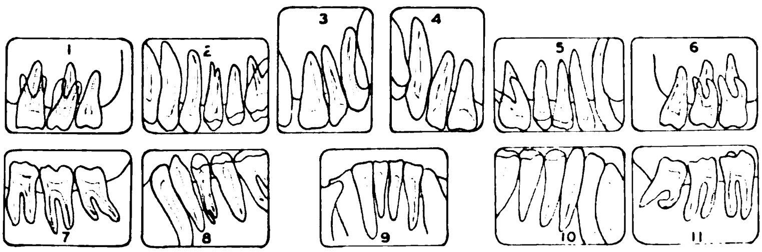

FIG. 146.—The teeth as shown on a set of eleven dental films.

A dental examination using fourteen films is more complete. In using this number, there is less likelihood of missing the apical regions of any of the teeth; all the teeth are shown in one direct view, and most of them in an additional more or less oblique view. In such an examination one film is used for each of the four molar regions (Films 1, 7, 8, 14, Fig. 147); one for each of the premolar or bicuspid regions (Films 2, 6, 9, 13); one for each of the four canine teeth including the adjacent lateral incisors (Films 3, 5, 10, 12), and one for the central incisors (Films 4, 11).

The directions given will be those for the fourteen-film examination. Necessary differences in technical details for the eleven-film examination will be included.

Except in the lower molar regions (C, Fig. 153), it is impossible to place dental films parallel with the long axes of the teeth. The films must be placed against the soft tissues of the inside of the mouth and against the crowns of the teeth. In this position the roots of the teeth and the more deeply placed portion of the films will be separated by a considerable space, the plane of the films and the long axes of the teeth forming an angle. Because of this, in dental roentgenography it is impossible to direct the rays perpendicularly to the teeth or to the films. They must be directed obliquely through the teeth, striking the films at an angle. This causes distortion of the images on the films. The rays must be directed in such a way that this distortion will be reduced to a mini-

mum, the images appearing as nearly as possible the exact size and shape of the teeth.

Dental films must be placed in the patient's mouth by the technician. Dexterity in this phase of dental roentgenography seems

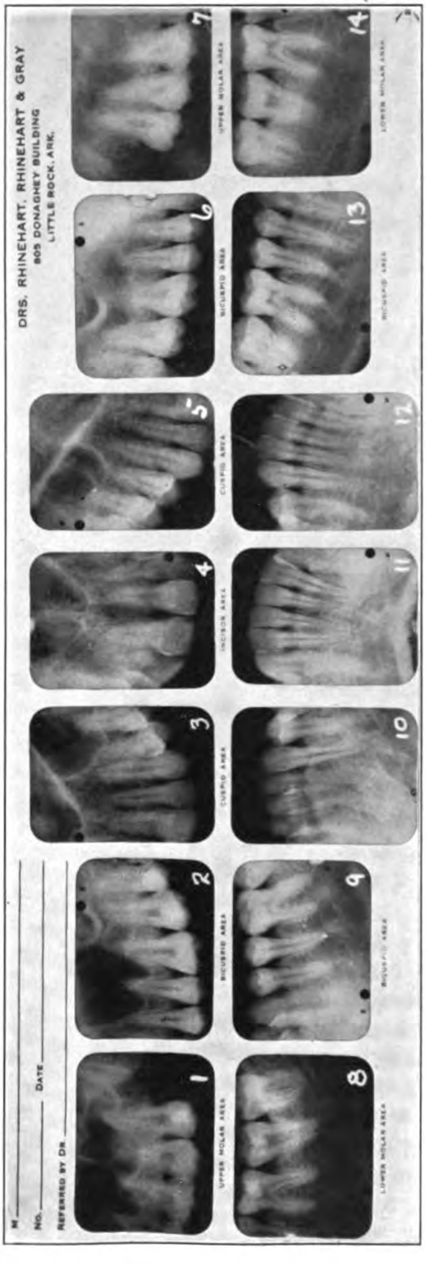

Fig. 147.—The teeth are shown on a set of 14 dental films. The films are mounted with the lingual aspects of the teeth toward the observer.

difficult for many persons to acquire, and a lack of it probably is one of the factors that contribute to the prevalence of dental films of poor quality. Written instructions are far inferior to a demonstration; but by following those that are given in this chapter, it is believed that skill may be acquired in this work.

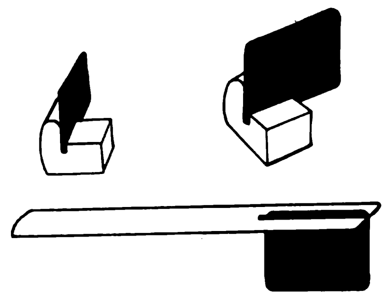

Fig. 148.—A block dental film holder and one made from a wooden tongue depressor.

No mechanical film holder has been invented that is as satisfactory for holding films in the mouth during exposures as the patient's fingers and thumbs. Films for the upper teeth should be held by the opposite thumb of the patient, the fingers of that hand being closed or extended and held against the face, exerting enough pressure to steady the thumb against the film. Those for the lower teeth should be held in place by the index finger of the opposite hand with the palmar surface of the finger against the film, the elbow raised level with or above the head, and the thumb and other fingers closed. Because of stiff or painful joints or the absence of an extremity, occasionally some form of film holder must be used. The wooden block holder described by Sheldon and shown in Fig. 148 is a satisfactory form. The film is placed in the slit in the holder and put in place against the teeth, the patient biting on the projecting ledge. A simple device for this purpose that may be used in an emergency is a wood tongue depressor that has a narrow slot the length of a dental film cut in one end with a fine-bladed saw (Fig. 148). The film, fastened near one margin in the slot, is placed in position, the patient holding it by biting on the projecting edge of the tongue depressor.

While dentists expose films of the teeth with the patient sitting and larger laboratories may have dental chairs and special dental machines, smaller laboratories are not so equipped, the dental being but part of roentgenography done with a general purpose equipment. The technique given here is intended primarily for such a laboratory with the patient in the supine posture, but it can be adapted readily to the erect position and a special dental equipment.

The technical essentials that must be observed in roentgenography of the teeth may be grouped under four headings:

1. The position of the patient's head.
2. The position of the films in relation to the teeth.

3. The position of the x-ray tube and the angle of the incident rays.
4. The selection of the proper exposure factors.

THE POSITION OF THE PATIENT'S HEAD.

If a piece of cardboard be placed in the mouth in contact with the occlusal aspects of the teeth, it will lie in the occlusal plane of the dental arches. When the jaws are together, the occlusal planes of both dental arches will nearly coincide; but when the mouth is open, there will be an angle between the occlusal planes of the upper and lower dental arches.

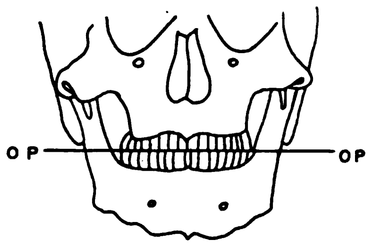

FIG. 149.—OP, the occlusal plane of the dental arches with the jaws closed.

The occlusal plane, either of the upper or lower dental arch as the case may be, is a plane used to determine the position of the patient's head on the table. This plane (OP, Figs. 149 and 150) always should be perpendicular to the top and at right angles to the long axis or to the length of the table (LA, Fig. 150). The thickness of the pillow under the head should be adjusted with the idea of keeping this plane in its correct position. In exposing films of different dental regions, the head will be turned on the neck, but the occlusal plane should be in the position indicated. When exposing films of the lower teeth, it often is necessary to lower the head and elevate the chin to bring the occlusal plane into the proper position. Adjustment of the patient's head always should be done after the film is in place. If done before, the head may be disturbed by movement while the film is being placed.

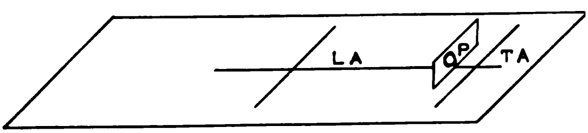

FIG. 150.—The correct position of the occlusal plane, OP, perpendicular to the table top and at right angles to its long axis, LA. The tube arm, TA, extends across the table also at right angles to the long axis of the table.

The amount of rotation of the head on the long axis of the body, or the degree of turning of the head on the neck, varies with the region being examined. By studying the illustrations, the proper position of the median plane of the head and the films with reference to the plane of the table top easily can be learned. When the molar

regions are being examined, the head is turned sideways so that the plane of the molar teeth is parallel with the table (A, Figs. 151 and 153). When the premolar teeth are being examined, the face is slightly elevated (A, Figs. 155 and 157). During the exposures of the canine and lateral incisor teeth the face is more nearly vertical (A, Figs. 159 and 161); and when films of the incisor regions are being exposed, the nose and chin are directed upward (A, Figs. 163 and 164).

These instructions for the position of the head should be understood thoroughly and carefully followed, for their observance will greatly simplify the position of the *x*-ray tube and the angle of the rays, probably the most difficult detail of dental roentgenography.

THE POSITION OF THE FILM AGAINST THE TEETH.

The film should cover accurately the teeth to be exposed, overlapping them by a safe margin on both sides. It should be placed so that its edge or side will be parallel with the line of the crowns of the teeth with which it is in contact. If this be not done, the images of the teeth will extend obliquely across the film. The edge of the film should not correspond exactly with the occlusal plane of the teeth but should project $\frac{1}{8}$ to $\frac{3}{16}$ inch. This will insure that all the crowns will be on the film. If the film cannot be seen after it has been placed and the head adjusted, it is always best to run the index finger along the occlusal surfaces of the teeth and the edge of the film to make sure that it has not been displaced.

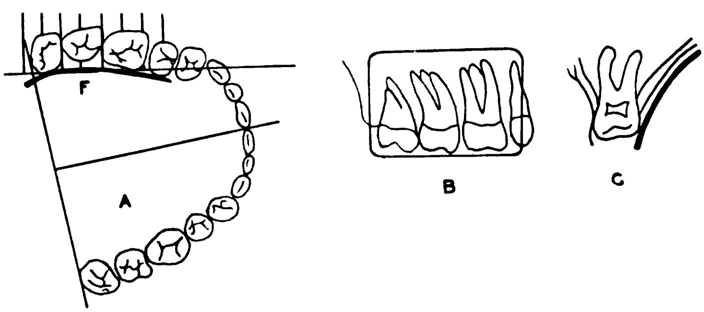

Fig. 151.—Position of the film for the upper molar teeth.

Certain regions present peculiar difficulties in the placing of the films. Those for the upper molar regions should not project farther forward than the middle of the second premolar tooth (B, Fig. 151). If this precaution be observed, there will be no danger of omitting a part of the third molar tooth. Because of gagging, some difficulty

may be experienced in placing films in this position. If care be taken to place the film in position as gently as possible without moving it over the palate, gagging usually will be prevented. When once begun, if the patient be instructed to take two or three quick, deep breaths through the open mouth, it may stop. In rare instances a patient will be encountered whose gagging reflex is so active that intraoral films cannot be taken without first anesthetizing the palate and pharynx.

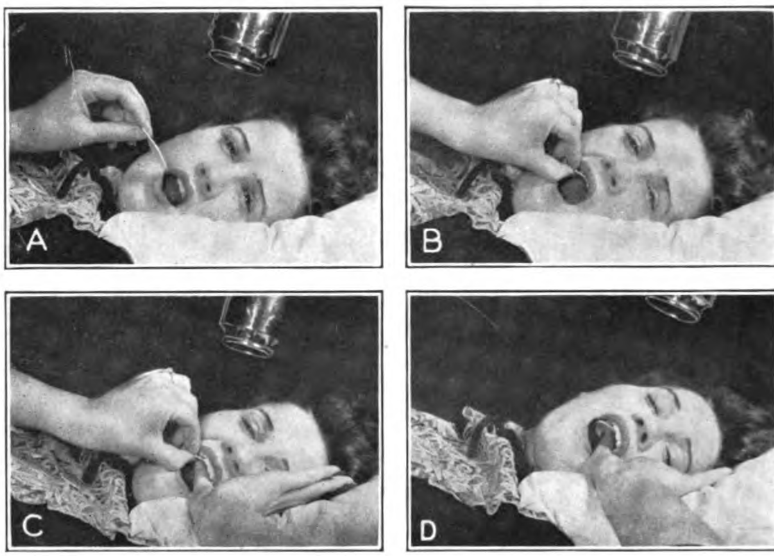

FIG. 152.—Placing the film for exposure of the upper right molar teeth. A, the film is held by the technician between the thumb and index finger of the left hand; B, it is held against the occlusal aspect of the teeth extending backward from the middle of the second premolar tooth; C, the patient's left thumb, guided by the right hand of the technician, turns the film against the teeth and palate; D, it is held in place by the patient's left thumb.

In placing films for the upper molar teeth, turn the patient's head so that the teeth to be examined are uppermost, stand on the side of the table facing the patient, grasp the superior anterior corner of the film (determined from the different aspects of the patient and not the technician) between the tips of the thumb and index finger of the opposite hand from the side of the patient being examined (left hand for right upper teeth, right hand for left upper teeth) (A, Fig. 152), and place the film in the patient's mouth with the inferior border along the occlusal aspects of the teeth from the middle of the second premolar posteriorly. At this step the film and teeth will form an angle of 90 degrees (B, Fig. 152). Then with the opposite hand guide the patient's opposite thumb into the

proper position in the mouth, causing the patient's thumb to turn the film from the right-angle position to the proper place alongside the teeth and lower part of the palate. If necessary, adjust the patient's head so that the occlusal plane is correctly placed and finally run the palmar surface of the index finger along the teeth and film margin to make certain that the film is correctly placed.

Films for the lower molar teeth must slip into the groove between the tongue and the gum (C, Fig. 153). If the tongue be retracted and the floor of the mouth relaxed, they can easily be slipped into position. If the floor of the mouth be not relaxed, pressure of the edge of the film against the rigid tissues will cause considerable pain. It often is necessary to explain and demonstrate what is meant by retracting the tongue, and occasionally the tongue must be pushed downward and backward out of the way.

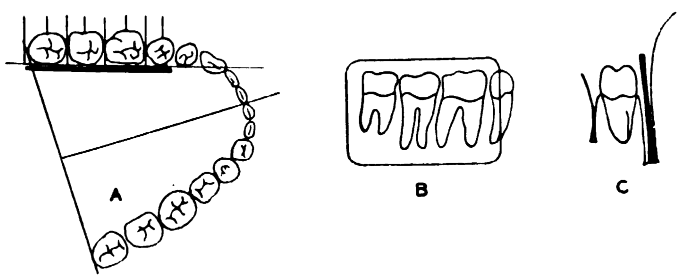

FIG. 153.—Position of the film for the lower molar teeth.

In placing films for the lower molar teeth, the technician stands in the same position as for the upper molars and holds the film between the index finger and thumb of the same side as that of the patient being examined (right hand for right teeth and *vice versa*). The film is placed in the mouth and inserted in the groove between the teeth and posterior part of the tongue. Then using the fingers of both hands, the one grasping the film and the index finger of the opposite hand, the film is gently worked downward in the groove into position. If difficulty be encountered, it may be necessary to work the index finger gently into the groove on the lingual side of the film. Often this assists in the relaxation of the floor of the mouth and moves the tongue out of the way. The gum on the lingual side of the necks of these teeth may form a ledge-like projection, or the mylohyoid ridge on the inside of the body of the mandible may be unusually prominent. Either of these may catch the edge of the film. Should this occur, the film must be dislodged toward the tongue before being pushed deeper into the groove. When in place, the anterior end of the film is at the middle of the second premolar

tooth. By holding the film with one hand, the other may be used to guide the patient's index finger into place against the film (Fig. 154). The patient's elbow should be elevated as high as the mouth or higher, the palmar aspect of the finger should be against the film, and the finger far enough back in the mouth to prevent the film from turning so that its posterior part is displaced upward. If the patient swallows after the film has been placed, its position usually is disturbed and it must be replaced.

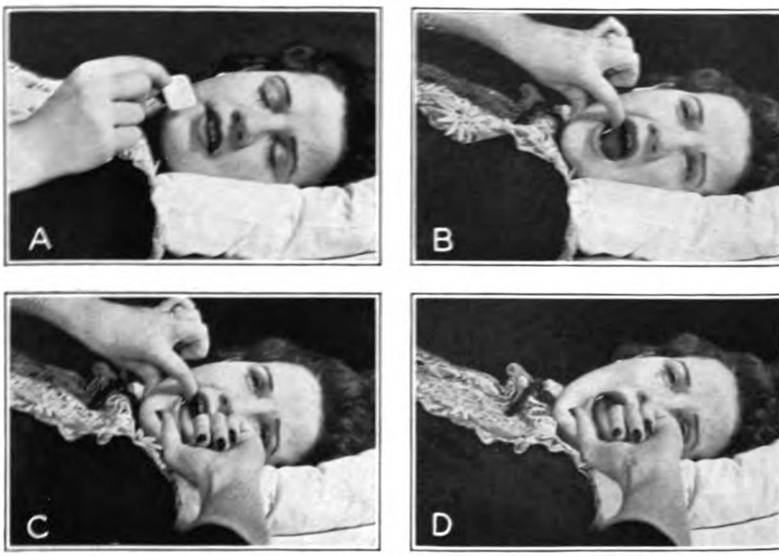

FIG. 154.—Placing the film for the exposure of the lower right molar teeth. A, the film is grasped between the thumb and index finger of the technician's right hand; B, it is inserted in the groove between the patient's teeth and tongue; C, it is worked into position by the technician's index fingers, and the patient's left index finger is guided into place against the film; D, the film is held while the exposure is being made.

If the jaw be short and a horizontally-placed impacted third molar tooth be present, either partially or completely covered by the jaw and gum, it may be very difficult to place a film in the groove in a position that will picture the entire tooth. Such teeth usually are more on a line with the crowns than with the roots of the second molars so that the placement of the film should be more backward than downward, even to the extent of having the film obliquely placed with the upper posterior corner higher than the occlusal surfaces of the teeth and with the other posterior corner covering the roots of the impacted tooth.

For the upper or lower premolar region the anterior margin of the film should be well over the canine teeth, projecting along the premolar teeth and including the first molar tooth posteriorly (A, Figs.

155 and 157). Often the best view of the first molar is obtained on this film. For this reason care should be exercised to see that it is included.

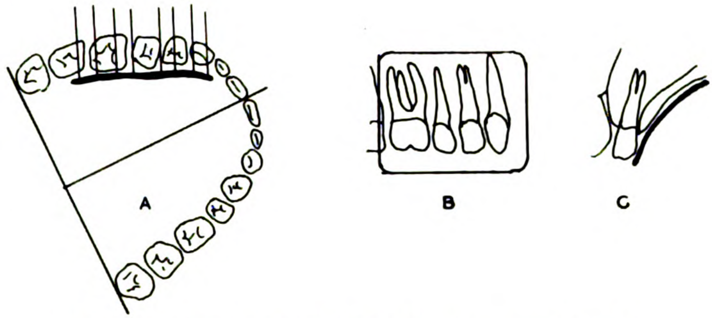

FIG. 155.—Position of the film for the upper premolar teeth.

FIG. 156.—Placing the film for exposure of the upper right premolar teeth. A, the film is grasped between the technician's left thumb and index finger; B, it is placed against the teeth covering the canine in front and the first molar behind; C, the patient's thumb is guided into position by the technician's right hand; D, the film is held in place by the technician's left hand during the exposure.

The placing of films for premolar teeth is not difficult. For those in the upper jaw the technician stands facing the patient and holds the film by its upper anterior corner in much the same way as for the lower molar teeth on the same side. It is placed against the occlusal aspects of the teeth extending forward over the canine tooth. It is maintained in position by the opposite thumb while

the thumb that originally held it turns it into position and presses it against the palate and teeth. This hand then is used to guide the patient's thumb into position (Fig. 156). The maneuvers for placing films for the lower premolar teeth are like those for the molar teeth of the same side (Fig. 158).

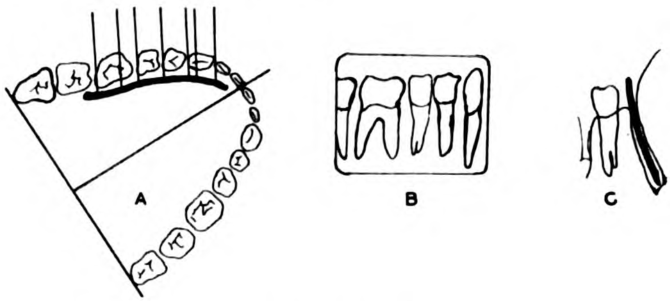

Fig. 157.—Position of the film for the lower premolar teeth.

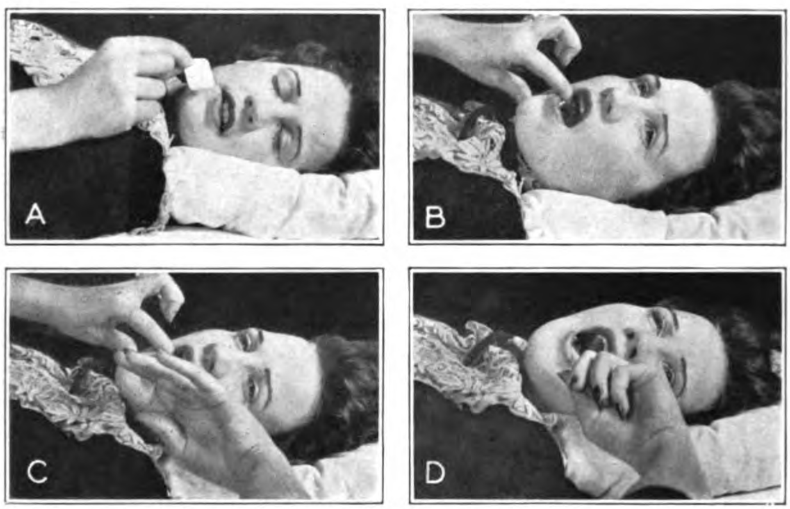

Fig. 158.—Placing the film for the exposure of the lower right premolar teeth; A, film is grasped between the index finger and thumb of the right hand; B, it is inserted in the groove between the teeth and the side of the patient's tongue. It is worked into position by the fingers of the operator and held by the index finger of the left hand; C, the patient's left index finger is guided into position, holding the film against the teeth; D, it is held in position by the finger of the patient's left hand.

Because of the length of the canine teeth and the curvature of the dental arches in these regions, dental films are placed with their long axes corresponding with the long axes of the teeth. On these films the adjacent lateral incisor teeth are included. The films should be placed with the anterior margins overlapping the central

incisor teeth (A, Figs. 159 and 161) with the posterior edge in the premolar region.

Placing films for the canine teeth in both the upper and lower jaws is done in the same manner as for the premolar teeth (Figs. 160

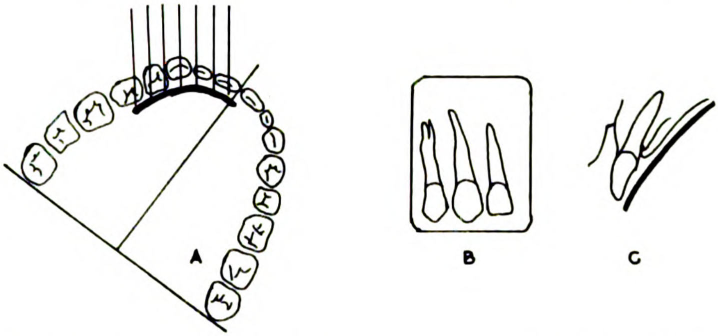

FIG. 159.—Position of the film for the upper canine and lateral incisor teeth.

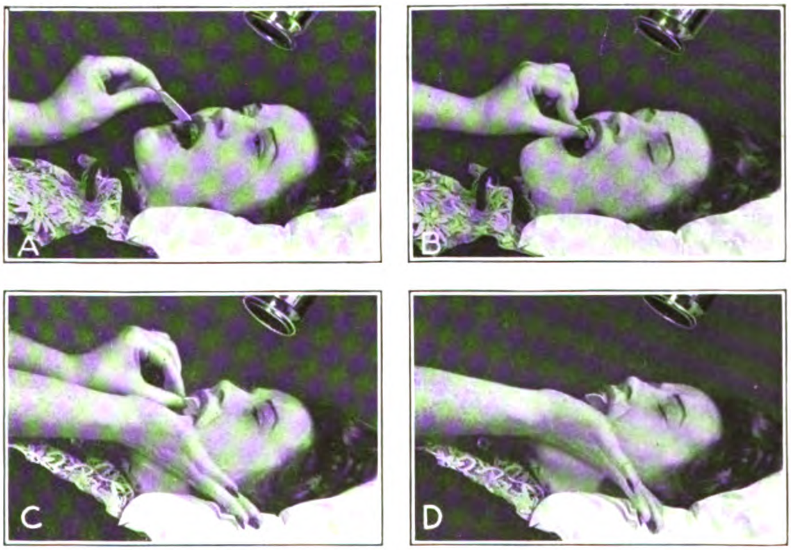

FIG. 160.—Placing the film for the exposure of the upper right canine and lateral incisor teeth, or for the upper incisor teeth. A, the film is held by the corner between the thumb and index finger of the left hand; B, it is held in the patient's mouth against the teeth with its long axis parallel with the teeth; C, the patient's left thumb is guided into position with the right hand of the technician; D, the film is held in place during the exposure by the patient's left thumb.

and 162). If the patient's finger be placed too deeply in the groove between the teeth and tongue when holding a film for the lower canine region, there is danger of the pressure of the finger sliding the film out of the groove. For this reason the pressure should be

such that it is against the crowns of the teeth or toward the bottom of the groove.

In the eleven-film examination of the teeth, the canine and both premolar teeth must be shown on the same films (Fig. 146). Because of the long roots of the canine teeth, the films should overlap more anteriorly than posteriorly. They should come far enough forward to cover the lateral incisors and even show at least a part of the central incisors. Otherwise the tips of the roots of the canine teeth and the periapical regions will not be included.

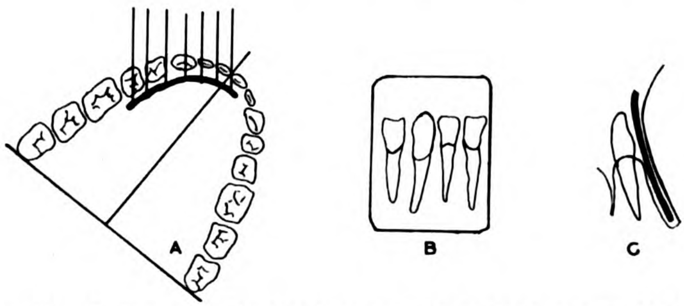

Fig. 161.—Position of the film for the lower canine and lateral incisor teeth.

Fig. 162.—Placing the film for the lower canine and lateral incisor teeth, or for the lower incisor teeth. A, the technician stands at the head of the patient and holds the film by the corner between the thumb and index finger of the right hand; B, it is placed in position between the teeth and the patient's tongue; C, it is held in position by the index finger of the patient's left hand for the exposure.

The upper and lower central incisor teeth are each included on a single film (A, Figs. 163 and 164). The long axes of the films are placed parallel with the long axes of the teeth, overlapping a similar amount on each side of the median plane.

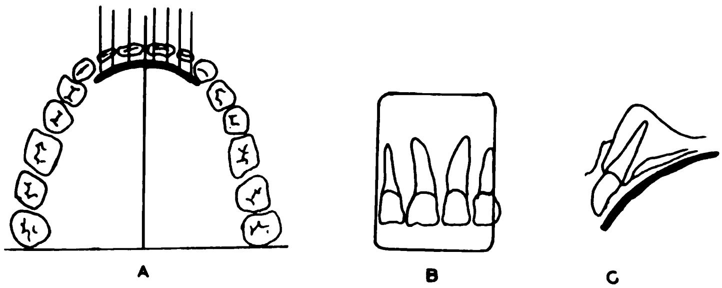

FIG. 163.—Position of the film for the upper central incisor teeth.

Usually it is not difficult to place films for the incisor teeth. Directions given for other upper teeth should suffice for the upper incisors. For the lower incisor teeth stand at the head of the table, facing the top of the patient's head. Before attempting to introduce the film, bend it over the finger to fit the curve of the teeth. Then grasp it between the index finger and thumb of the left hand, insert it into the groove with the aid of the opposite hand, and hold it with the left hand while the index finger of the patient's right hand is guided into position (Fig. 162).

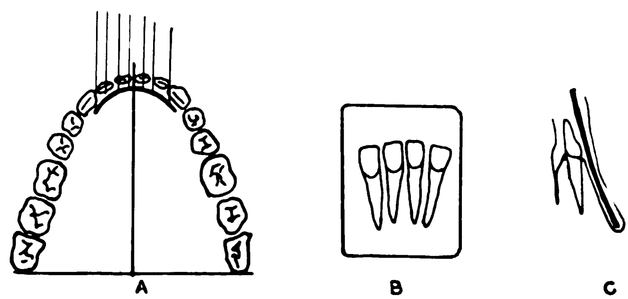

FIG. 164.—Position of the film for the lower central incisor teeth.

In the eleven-film examination of the teeth two films are used for the upper incisor region, one for each central and lateral incisor (Films 3, 4, Fig. 146). These are placed with their long axes parallel with the teeth, each overlapping the opposite central incisor on one side and the canine on the other. The lower incisor teeth are all shown on one film (Film 9, Fig. 146). It should be placed with its long axis horizontal, overlapping the canine teeth to an equal extent on both sides.

THE POSITION OF THE ROENTGEN-RAY TUBE AND THE ANGLE OF THE INCIDENT RAYS.

The rule that usually is given to govern the position of the x-ray tube and the angle of the central ray is: "The rays should be directed perpendicularly to a plane which bisects the angle formed by the plane of the film and the plane of the long axes of the teeth." This is the correct rule; and if it could literally be followed, there would be no occasion for shortening or elongating the shadows of the teeth from improper angulation of the incident rays. However, as pointed out by Simpson, when the film is in position in the mouth, it is to a greater or less extent invisible; the plane of the teeth can only be surmised by the position of the crowns, the plane to which the rays are to be directed is imaginary, and the rays themselves are invisible, the direction of their propagation being indicated by the position of the cone in the tube stand.

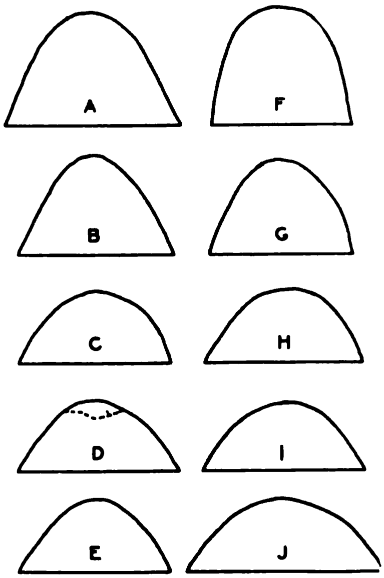

FIG. 165.—Variations in the contour of the hard palate. These curves were obtained by bending a thin strip of lead against the palate at the level of the space between the upper first and second molar teeth.

Because of the difficulty of applying the rule as given in the preceding paragraph, numerous attempts have been made to ascertain the correct angulation of the incident rays. The reported results differ, sometimes to a rather striking degree. Perhaps this divergence may be due to different factors; one may be measured with the films closely approximated to the mouth contours while another may be based on a flat, unbent film. To one examiner teeth shadows that are slightly shortened may be preferred, while another may like a similar amount of elongation. If the films be held against the crowns of the teeth or against the mouth nearest the roots, there may be a difference. Actual measurements made under exact, controlled conditions have not been encountered.

The chief factors that enter into the determination of the angle of the incident rays are the height of the palate in the molar region, the length of the teeth, and the inclination of the teeth in the alveolar

processes of the jaws. There are important differences in the height of the hard palate in the upper jaws of different persons that have a decided effect on the angle to which the tube should be tilted. Fig. 165 shows these differences. These curves were made by molding a thin strip of lead to the inside of the palate at the level of the space between the first and second molar teeth. The illustration shows the types of palatal curvatures that are encountered, both average and extreme.

The length of the teeth and their inclination in the alveolar processes also have an influence on the angle of the incident rays. Longer teeth will require a greater angle than shorter teeth, and those that have a decided inclination, forming an angle with the occlusal plane, will also require a greater angulation of the incident rays. There is no way of determining the length of the teeth by inspecting their crowns. The inclination of the teeth usually can be determined. It is most pronounced in the anterior teeth, particularly in the upper jaws.

These considerations require that the angle of the incident rays be varied for different patients and often changed for the various regions of the same patient.

For the upper teeth the angulation of the tube is above the occlusal plane. The occlusal plane of the upper teeth must be perpendicular to the table top and at right angles to its long axis. The tube arm must extend at right angles to the long axis of the table. Under these conditions the tilt of the tube for the angle of the incident rays for the upper molar teeth will, in a measure, depend on the height of the palate in the molar region. The angle will vary from 20 degrees for the highest to as much as 40 degrees for the broad, low palates. An angulation of 25 to 30 degrees will suffice for the average patient.

This angle should be kept as small as possible. By so doing there is less likelihood of superimposing the shadow of the malar bone over the shadows of the roots of the molar teeth, thus obscuring the roots and the periapical regions of these teeth. In many patients, particularly those with low palates, in the usual dental roentgenogram it is impossible to prevent this superimposition of shadows. To overcome this difficulty, LeMasters advocated the fastening of a cotton roll with celloidin along one side of the film. In place in the mouth, this roll is held against the crowns of the teeth, separating the film from the teeth at the crowns but permitting the film to be held against the palate along its other side. This permits of the use of a much smaller angle of the incident rays; the rays pass under the malar bone, and the roots of the molar teeth are shown unobscured. Brandison has recently devised and described a block to

be used for films of the upper molar teeth. A wedge-shaped block is made to fit against the crowns of the teeth separating the crowns from the film like the cotton roll of LeMasters. It permits of the use of a 20-degree tilt of the tube thus directing the rays beneath the malar prominence.

For the upper premolar teeth the angle of the incident rays above the occlusal plane is about the same as for the molar teeth, usually from 25 to 35 degrees. The smaller angle may be used if the palate be high, and the larger angle for a low palate in the region of the roots of these teeth. Because of the length of the canine teeth and because these teeth usually incline backward to some extent, a greater angle is required. This should vary from 35 to 45 degrees, the smaller angle for vertically placed teeth; the longer for the sharply inclined teeth, with 40 degrees for the average. An angle of 35 to 40 degrees should be used for the upper incisor teeth.

Less difficulty will be encountered in selecting the correct angulation of the tube and the incident rays below the occlusal plane for the lower teeth. With the occlusal plane perpendicular to the table and at right angles to its long axis, for the lower molar teeth the tube need not be tilted. In this region it is possible to place the films parallel with the teeth and project the images directly on to the films. For the other lower teeth the tube must be angulated. With the film held firmly against the jaw over the apical regions of the teeth, an angle of 10 degrees for the premolar teeth, one of 20 degrees for the canine teeth, and one of 15 to 20 degrees for the incisor teeth will be correct. If the film be held against the crowns of the teeth instead of against the jaw over the lower parts of the teeth, there may be a separation of the film from the jaw at its inferior edge. To give undistorted images, this will require a greater angulation of the tube.

In the exposure of all dental films the position of the head and the tube should be such that the rays will pass directly between the teeth and parallel with their proximal planes. One exception to this must be noted. In order to include the canine and both premolar teeth on one film in the eleven-film examination of the teeth, the rays must be directed with a dorsal inclination, more through the apex of the canine than through the tips of the premolar teeth. This will give a more distorted image, but the shadows need not be superimposed.

When making exposures of the lower teeth, usually enough of the film can be seen to permit accurate centering of the tube even when a small cone is used. This is not true for the upper teeth. There are certain landmarks that can be used for this purpose. The roots of

the upper teeth will be found under a line extending directly backward from the inferior margin of the ala of the nose. A second line at right angles to this and passing through the lateral margin of the orbit will be over the root of the first molar tooth, with the second and third molar teeth immediately posterior. The premolar teeth are located on this horizontal line at its junction with one passing through the middle of the eye, while the apex of the canine tooth is on the same line about one-fourth of an inch lateral to the ala of the nose (Ennis).

Occasionally patients are encountered whose heads cannot be placed in the proper position. These are corpulent persons with short thick necks and those suffering pain from a neuritis or other conditions in the neck and shoulders. With them the difficulty will be in the turning the head far enough sideways to have it in the proper position for the exposure of the posterior teeth with a single tilt of the tube. When this happens, the deviation of the head from the proper position must be compensated for by also tilting the tube toward the face. If this be required, the tilt should be such that the rays pass directly through the proximal spaces between the teeth.

INTRAORAL ROENTGENOGRAPHY WITH BITE-WING FILMS.

A roentgenographic examination of the teeth that is very useful is made with bite-wing films, a special form of dental film designed

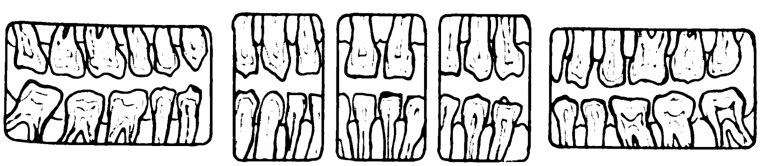

FIG. 166.—The teeth as shown on a set of bite-wing films.

by Dr. Howard R. Raper. These films are used in the search for dental decay or caries, for degenerative changes in the pulp, and for the condition of the bone margin around the necks of the teeth. On these films the images of the crowns and necks of the teeth are projected without the distortion present on the usual dental roentgenograms (Fig. 166).

A bite-wing differs from the intraoral dental film in size and shape and in that it has a projecting bite-tab on which the patient bites to hold the film in position. These films are produced in four

sizes, three for the examination of the teeth of adults and one special size for children. Of the three adult-size films two are used for the molar and premolar regions, the smallest size being used in the anterior part of the mouth.

The technique for the use of these films is quite simple. The film, of the size used for the region to be examined, is placed in the mouth on the inside of the teeth with the bite-tab projecting between the teeth. By means of the tab the film is approximated to the surfaces of the crowns of the teeth. The patient bites on the tab, thus holding it securely in place during the exposure. With the occlusal plane of the teeth perpendicular to the table top and with the teeth and film parallel to the table top, an angulation of 10 degrees in a downward direction is the correct inclination for the tube and the correct angle of the incident rays.

OCCLUSAL ROENTGENOGRAPHY.

Another special kind of examination of the teeth that has a definite field of usefulness is made with occlusal dental films—films that are 2½ by 3 inches in size. These are especially designed to be held between the teeth for examinations of the upper and lower jaws, the upper and lower teeth, and for examination of the sphenoid sinuses as described by Pfahler. Malpositions of the teeth, large areas of disease, such as cysts, and other gross lesions are shown to best advantage on such films. A special intraoral dental cassette fitted with double intensifying screens has been designed by the Eastman Kodak Company for the exposure of such films. Special moisture-proof envelopes of celluloid-like material are provided with the cassette.

In exposing films of the sphenoid sinuses with such films, with or without the cassette and screens, the film is placed as far back as possible in the mouth with the long axis in the median plane of the head. The rays from a small cone are directed toward the surface of the film at an angle of 10 to 12 degrees behind the vertical, the central rays entering at the junction of the coronal and sagittal sutures of the skull. This junction occurs in the median plane directly above a point just in front of the external auditory meatus. A properly exposed film will show the sphenoid sinuses on the posterior part and the upper dental arch on the anterior part of the film (Fig. 167, A).

For an occlusal view of the upper dental arch the film is placed in the mouth with the long axis transverse. The rays are directed perpendicularly to the film through the median plane of the head

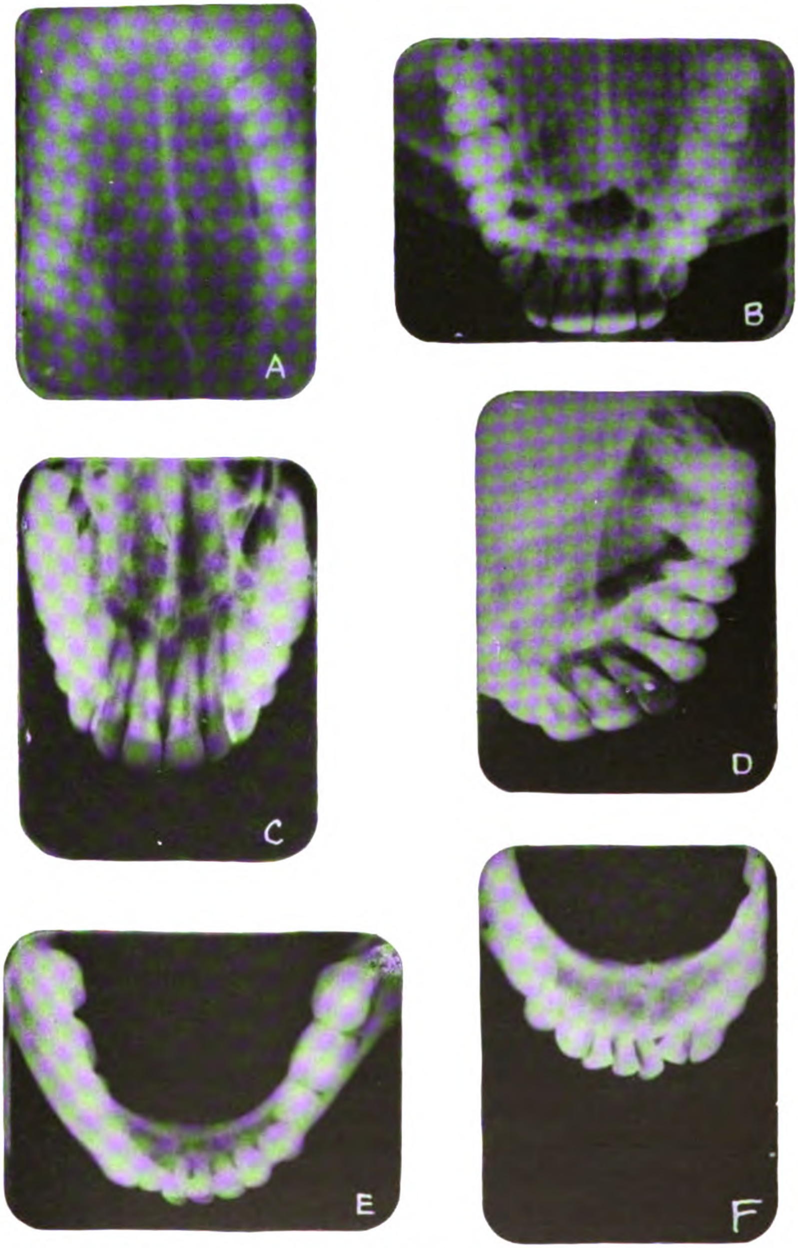

FIG. 167.—Films made with occlusal dental films. A, sphenoid sinuses by the method described by Pfahler; B, occlusal film of the upper teeth; C, upper anterior teeth; D, one side of the upper dental arch; E, occlusal film of the lower teeth; F, the lower anterior teeth. B, C, and D are useful exposures in examining the hard palate and alveolar processes of the maxillæ for fractures. E is an excellent exposure for calculi in the submaxillary or sublingual ducts.

in a transverse plane through the lateral extremity of the orbits. All the upper teeth and the hard palate will be shown on a properly exposed film (Fig. 167, B). Other exposures may be made of the upper teeth with the long axis of the film in the median plane by tilting the tube backward at an angle of 65 degrees and centering the rays through the tip of the nose (C), and by tilting the tube backward and medialward at angles of 60 degrees and centering through the canine fossa (D). The first of these films will show the anterior teeth; the second all the teeth on one side of the upper dental arch.

By placing the film in the mouth with the emulsion side down and with the long axis transverse, an occlusal view of the lower teeth may be taken. The head is tilted until the occlusal plane and the film are perpendicular to the table top. The tube is centered below the chin in the midline of the neck halfway between the angles and the symphysis of the mandible (Fig. 167, E). For the anterior teeth the angulation toward the film is 55 degrees with the rays centered over the symphysis (Fig. 167, F). For the molar region the film is placed in the mouth with its long axis in the median plane. The rays are directed perpendicularly to the surface of the film through the jaw just below the second molar tooth.

EXPOSURE FACTORS.

The *x*-ray tube used in dental roentgenography should have a small focal spot. Usually a short anode-film distance is used. This may vary from 8 inches for some of the dental machines to as much as 16 to 20 inches for the larger equipments. With the cone close to the face, the special dental cones made for large tube stands usually give a distance of 16 to 18 inches.

In exposing dental films a relatively large quantity of rays as represented by the milliampere-seconds of the exposure and a low voltage will give the best results. The time should be the variable factor with the voltage and milliamperage kept constant. The proper factors should be determined by trial exposures. If the time for the upper molar teeth be found to be five seconds with a certain voltage and milliamperage, proper exposures for the other regions will be as follows: Four seconds for the upper premolar teeth, three seconds for the upper canine teeth, three and a half seconds for the upper incisor teeth, four seconds for the lower molar teeth, three and a half seconds for the lower premolar teeth, and three seconds for the lower canine and incisor teeth.

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CHAPTER XVIII.

THE THORACIC VISCERA.

THE thoracic viscera may be divided into two groups; in one are the pleural membranes and the lungs and the other includes those structures which form the mediastinum. Structures in the mediastinum of roentgenographic importance are the heart and thoracic aorta, the pericardium, the esophagus, and the thymus gland. In some instances the mediastinal lymph nodes require consideration.

The lungs are elastic, air-filled organs accurately filling the space in the thoracic cavity on each side of the mediastinum. They project for a variable distance above the clavicles into the neck. At their bases they are in contact with the upper surface of the diaphragm which separates the right lung from the liver and the left from some of the abdominal viscera, chief of which is the fundic portion of the stomach. Since the liver rises higher than the stomach, it follows that the right arch of the diaphragm and hence the base of the right lung are higher than the left, making the right the shorter lung. Because that part of the mediastinum occupied by the heart and pericardium bulges farther into the impression in the left than it does into the right lung, the left is narrower and smaller than the right. Except at the roots, each lung is covered by a double layer of pleural membrane that permits of movement of the lungs in the expansion and contraction of the thorax.

The largest and most important constituents of the mediastinum are the heart and aorta. The heart within the pericardium makes up the inferior and anterior part of the mediastinum and extends laterally beyond the limits of the other structures to fit into impressions in the lungs. Like the lungs, the heart is covered with a double layer of serous membrane, the pericardium, which permits of its movement on surrounding structures. From the base of the heart the aorta extends upward, arches backward and slightly to the left along the side of the body of the fourth thoracic vertebra, then turns downward behind the root of the left lung and in front of the esophagus to leave the thorax through the aortic opening in the diaphragm.

The esophagus is the most posterior of the mediastinal structures. It enters the thorax at the inlet above and extends through its entire length, lying just anterior to the thoracic vertebræ (Fig. 181). In its upper part it is located in the midline, deviating slightly to the left in its lower extent. The trachea is located anterior to the

esophagus in the upper part of the thorax. It extends from the inlet as far as the fourth thoracic vertebra, where it divides into the two main bronchi which almost immediately become constituents of the lung roots. The thymus gland is located in the upper part of the anterior mediastinum. Except in infants and young children, it rarely is of large size or of clinical importance. The mediastinal lymph nodes, most numerous around the trachea and bronchi and extending lateralward into the lung hiluses, are never of roentgenographic importance unless considerably enlarged.

There is a variation in the shape of the bony wall of the thorax and of the thoracic viscera which is not due to differences in the size of different individuals. On the contrary, it is due to differences in body architecture, for which the general term habitus, meaning body shape or appearance, is used. Mills has attempted to classify the habitus of a large number of persons and to point out the differences in the body shape and the shape of the viscera in the various types. He recognized two dominant types, four major types, and a number of subtypes (Fig. 176). The two dominant types are the hypersthenic and asthenic. An individual of the hypersthenic habitus is one with a massive and powerful physique, of great body weight, and with a heavy bony framework. The thorax is short, wide, and deep. The ribs are directed more nearly horizontally than in any other type. The subcostal angle is obtuse and the xyphoid cartilage is broad. The lungs are widest and bulkiest at the base and contracted at the apices. They project but little above the clavicles into the neck. The arches of the diaphragm are high so that much of the lungs is located behind and below the highest parts of the diaphragm. The long axis of the heart is nearly transverse to that of the body and part of the heart often is below and behind the highest part of the diaphragm (Fig. 177).

An individual of the asthenic is the antithesis of one of the hypersthenic habitus. The body is frail and slender, light in weight, with delicate bones. The thorax is long and narrow (Fig. 176). There is a marked downward slope to the ribs. The subcostal angle is acute. The lungs are widest in their upper zones and reach well above the clavicles into the neck. The diaphragm slopes downward. The heart is pendant, with its long axis nearly vertical and near the midline, a condition too often called a "drop" heart. Practically all of the lungs and the heart are located above the highest limits of the diaphragm (Fig. 177).

Not many belong to the two dominant types of body habitus. Most individuals are between these two extremes. If a large number of persons be arranged according to the type of habitus, from the hypersthenic at one extreme to the asthenic at the other, probably

all degrees of variations will be found. In visceral roentgenography it is important to keep in mind the variations in habitus with the differences in the shape and position of the viscera directly traceable to them.

THE LUNGS AND PLEURÆ.

Roentgenologic examination is of the utmost importance in detecting the presence and extent of disease within the lungs and pleuræ. To enumerate the conditions in which it is useful would be to make a list of the diseases of these structures in which there are macroscopic pathological changes.

Roentgenologic examination of the lungs should be both fluoroscopic and roentgenographic. Intelligent fluoroscopic examination of the lungs is an art acquired only by long experience. Essentials in equipment are a vertical and a horizontal fluoroscope, or preferably a tilting apparatus by which examinations can be made in erect, horizontal, and intermediate positions. The fluoroscopic room should be completely dark, illuminated preliminary to and at pauses in the examination by a low-wattage ruby globe. At best the images seen on a fluoroscopic screen are dim. This requires a complete dilatation of the pupils of the eyes before the examination is begun. This may be accomplished by remaining for ten minutes in total darkness. If opaque glasses be worn while preparation for the examination is being made, the time required for the proper accommodation of the eyes is shortened.

By following a routine procedure during fluoroscopy, all parts of the lungs are examined in sequence and the possibility of overlooking an important detail is decreased. Whenever possible, a patient should be examined in the erect posture with all the clothing removed or clothed only in a garment known to be completely radiolucent. The shoulders should be rotated forward to remove the shadows of the scapulæ from the lung fields. Perhaps a general survey of the entire thorax and neck with a relatively wide diaphragm opening should initiate the examination. Then the diaphragm should be closed to a narrow opening and the apices and infraclavicular regions carefully examined. This should be done during quiet and forced respiration. On each side the momentary expansion and lighting of the lung with coughing should be studied. From the apical region the examination should proceed to the rest of the lung fields. In the bases the contour of the diaphragmatic arches should be examined and the movements of the diaphragm studied. In examining the costophrenic sinuses, the patient should be rotated into a semilateral posture for inspection of their posterior portions. Finally the patient should be turned, and the examination repeated with the fluoroscopic screen at the back.

During such an examination the attempt is made to locate infiltrations and other lesions within the lungs. When found, they should be studied from different angles as to their location, their character, the probable nature of the pathological processes causing the abnormal shadows, and finally as to the probable type of disease process that is present. During fluoroscopy the kind of subsequent roentgenographic examination that is to be made should be decided.

Roentgenograms of the lungs are made to register on the films the shadows of the pathological processes so that they may be studied in detail, and as a permanent record for comparison with those of later examinations. While gross lesions in the lungs often can be identified with the fluoroscope, fluoroscopy should never be depended on in searching for early tuberculous infection nor for furnishing the details of any type of pathological process.

Roentgenograms of the lungs and pleuræ may be made in the antero-posterior, the postero-anterior, right or left lateral, or oblique directions. The most useful of these views and the one most often taken is in the postero-anterior direction, with the cassette and film along the front of the chest and the tube at the back. This position brings the heart closest to the film, thus giving the least distortion of its image; since the anterior part of the chest wall is thinner than the posterior, it brings the lungs slightly closer to the film, and it enables the shoulders to be rotated forward around the thorax, projecting the shadows of the scapulæ laterally away from those of the lungs. The erect or prone position may be used. Routine antero-posterior views should be taken only when the patient is too sick to be turned to the prone position.

Evans, LeWald and Green, Pritchard, and Chapman emphasize the importance of lateral and oblique roentgenograms of the chest. In the antero-posterior plane they are of unquestioned value in the location of isolated pathological lesions of relatively large size, such as lobar pneumonias, lung abscesses, pulmonary cavities, interlobar accumulations of fluid, etc.

There is considerable difference of opinion whether or not routine films of the lungs should be made stereoscopically. Dunham and others emphasize the importance of stereoroentgenograms. Chapman says that at the Stanford Medical School stereoscopic films are not made as a routine, but a lateral film is taken in addition to the postero-anterior view. Holmes and Ruggles say that stereoscopic films are not necessary as a routine procedure, while Wessler and Jaches emphasize the greater importance of a good single plate or film in preference to a mediocre stereoscopic set. Stereoscopic films of good quality are preferable to a single film of equal quality,

particularly in examining for early tuberculosis. In the examination of gross lesions a postero-anterior and a lateral film probably are preferable to a single stereoscopic pair.

Since the horizontal position causes engorgement of the pulmonary vessels and interferes with respiration, whenever possible postero-anterior films of the lungs should be taken with the patient in the erect position, either sitting or standing. This is especially important in examining those who have a protuberant abdomen. If the abdomen be large, placing the patient in the prone position will force the abdominal contents and fat into the lower part of the bony thorax and elevate the diaphragm, thus diminishing the expansion of the thorax and lessening the part of the lungs that will be shown on the film above the diaphragm. The erect position necessitates a device to support the cassette while the exposure is being made. Any one of the vertical stereoscopic plate changers, or even a homemade device that may be raised and lowered, will serve for this purpose.

In exposing such films, the cassette is placed in the holding device and adjusted so that the extended chin just reaches the top of the film in the cassette. The tube is turned with the rays directed horizontally. The patient is placed against the front of the cassette or the cassette holder with the chin elevated and both shoulders rotated forward until the arms and shoulders are also in contact with the cassette or cassette holder. The elbows are bent; the hands and wrists are in the region of the hips. Perhaps the most comfortable position is with the wrists flexed and the backs of the hands against the hips. The shoulders also should be depressed as much as possible which will depress the clavicles and prevent their shadows from crossing the apices of the lungs. This may displace the backs of the hands downward off the hips to the regions of the greater trochanters of the femora (Fig. 168). A band that may be fastened across the patient's back to assist in immobilization is of considerable value. The anode of the tube should be at the height of the patient's fifth or sixth thoracic vertebra, directing the rays into the thorax at this level. A full inspiration—not the fullest that the patient can take, but the fullest that does not cause straining—should be taken and held while the exposure is being made.

The same position also is used for stereoscopic postero-anterior films of the lungs. The patient takes this position in front of the automatic plate changer, takes a full inspiration, and the first film is exposed; the films then are changed, the tube is shifted, and the second film is exposed—all of this taking place while the patient holds the breath and remains immobile. The tube shift should be in the vertical direction, the amount of shift depending on the anode-film distance (page 210).

The position of the film and patient for postero-anterior films in the prone position should be the same as that for the erect posture.

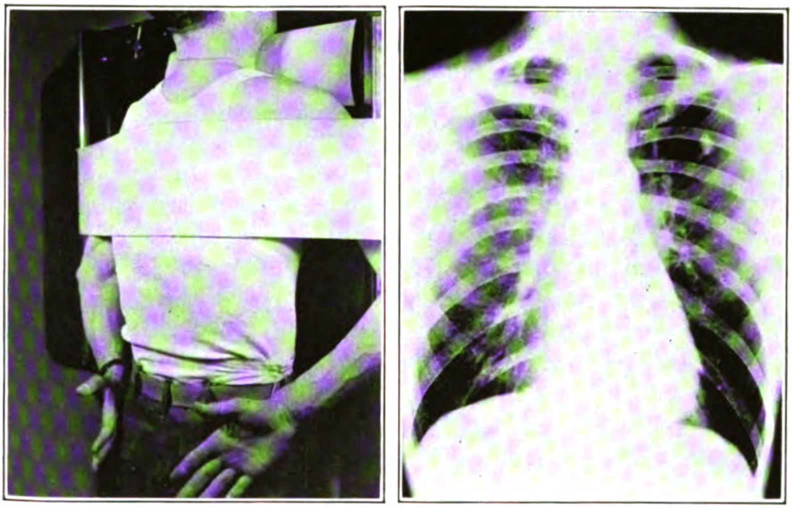

FIG. 168.—Single or stereoscopic postero-anterior exposure of the lungs with the patient erect. The shoulders are rotated forward and depressed; the rays are directed horizontally through the fifth or sixth thoracic vertebra.

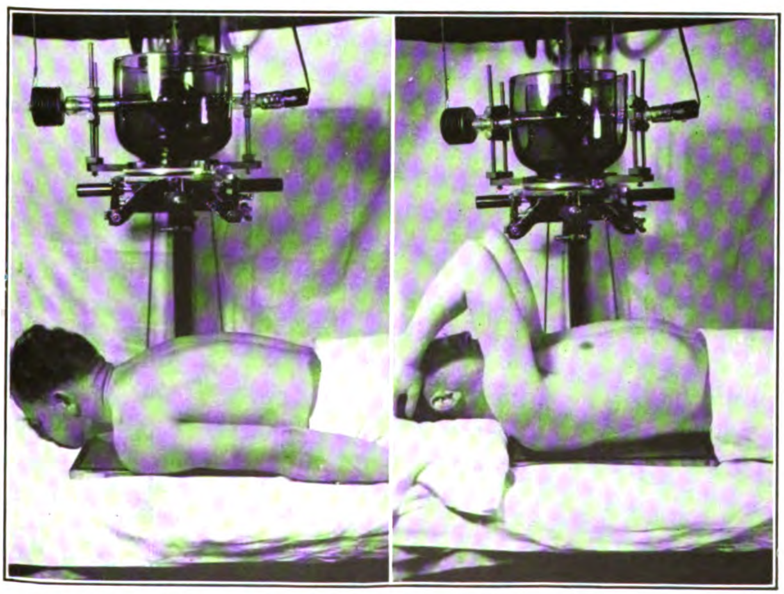

FIG. 169.—Positions for exposures of the lungs with the patient horizontal. On the left, the position with the patient prone; on the right, with the patient supine. The erect position (Fig. 168) is the best. The prone position may be used when the patient is unable to stand, the supine position being used only with those patients who are unable to stand or are too ill to be turned to the prone position.

The chest is placed on the cassette, the chin is extended so that it is just off the top of the film, the upper extremities are placed at the sides, and the shoulders are dropped forward and depressed (Fig. 169). The exposure is made at full inspiration. Films in the lateral direction may be exposed with the patient standing or lying on the side. In either case the lung to be examined especially must be nearer the film. By extending both upper extremities above the head, more of the lung fields will be uncovered by the shoulders than in any other position (Figs. 111 and 170). In the erect posture immobilization by a band around the chest is essential. In exposing films in the supine position, clasping the hands behind the head and bringing the elbows forward over the face as far as possible will rotate the scapulæ forward so that their shadows will not cover a part of the lung fields (Fig. 169). All lung films should be exposed with respiration suspended during full inspiration.

The kind of roentgenologic examination that should be made of a given patient depends largely on the condition of the patient and the type of disease that is present. In an office practice where almost all patients are ambulatory, a fluoroscopic examination in the erect position should first be made. If marked evidences of disease be found, single or stereoscopic films in the postero-anterior direction with the patient in the erect position should then be taken. Oblique or lateral views also are important in accurately locating many gross lesions. If no lung involvement be seen with the fluoroscope, and, as is so often the case, the examination is being made to detect or eliminate a tuberculous infection, postero-anterior stereoscopic films in the erect position should be taken. When dealing with those that are acutely ill and unable to stand, fluoroscopy may be performed with the patient in the supine position. Since incipient pulmonary tuberculosis rarely is sought under such conditions, single films in the supine or prone position may be taken. If a gross pathological lesion be found in one side, considerable diagnostic information often can be obtained from a lateral or oblique view of the thorax. The best position for this view may be determined during the fluoroscopy. The patient should be in the same position relative to the film that showed the lesion best with the fluoroscope, the cassette and film replacing the screen in each instance, with the involved side nearer the cassette.

In seeking a fluid level in a suspected hydropneumothorax or lung abscess, or in examining a patient for shifting of the fluid in a suspected pleurisy, a postero-anterior film with the patient in the lateral position may be made by placing the cassette against the front of the chest and directing the rays horizontally. For patients

having pleural effusions, Riegler places the patient, supported on cushions, with the affected side down, the cassette being placed at the edges of the cushions. In this way the entire thorax is included on the film. The inferior arm is placed above the head, the superior arm holding the cassette in the vertical position (Fig. 170). Brown

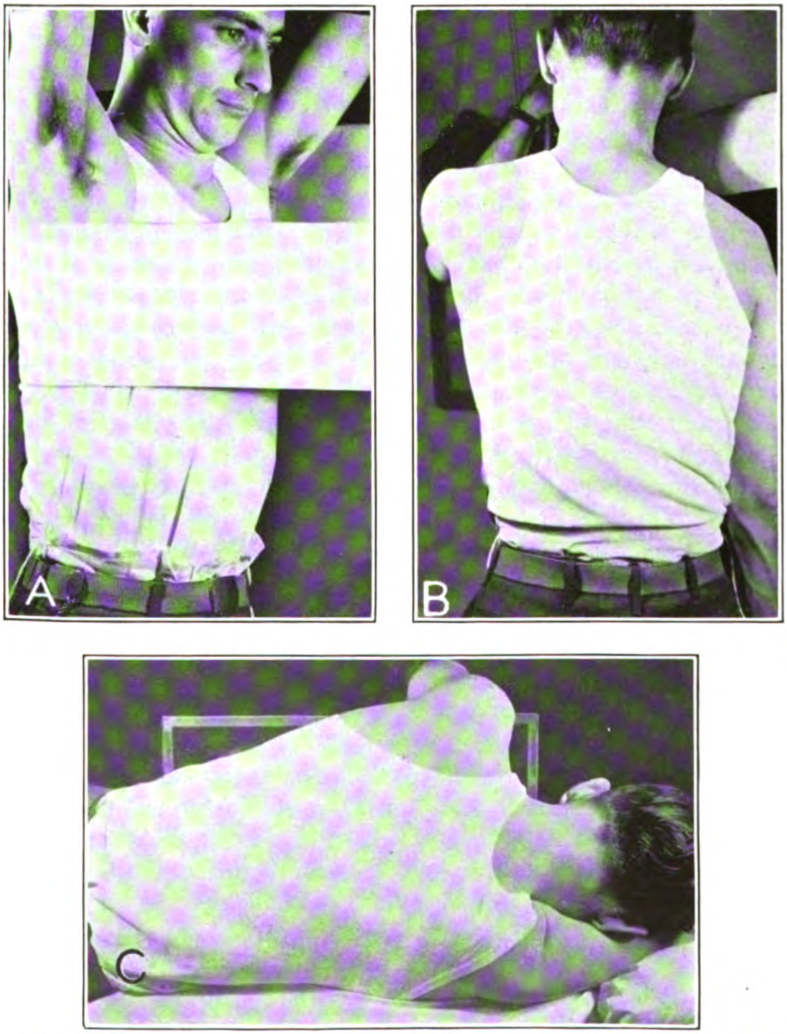

FIG. 170.—A, position for a lateral exposure of the thorax with the patient erect. The upper extremities are extended over the head. B, position for a right anterior oblique exposure of the thorax. C, position for a postero-anterior exposure of the thorax with the patient in a lateral position. A non-opaque pillow is placed lengthwise under the body, the film is held vertically in front of the thorax and the rays are directed horizontally. This is the position recommended by Riegler for small pleural effusions. A similar position is satisfactory for postero-anterior exposures of the abdomen when the patient is unable to stand.

advocates the use of a 2-inch platform with a slot along one side to hold the film in the upright position with its margin projecting beneath the underneath side of the chest. To permit the heart to drop toward the uninvolved side, he places the patient on that side, thus showing the involved lung to better advantage.

All views of the lungs of adults should be made on 14- by 17-inch films. Those of children may be made on smaller films.

When a patient has a disease process of considerable density involving a portion of one lung, the film made in the usual manner, if taken with factors appropriate for the normal lung, will give an underexposure of the diseased side. On the other hand if the factors be those for the portion of increased density, the normal lung will be overexposed. To equalize the exposure of the two sides, the intensity of the rays directed at the normal side may be diminished by filtration with aluminum or by workable plastic material. A relatively simple procedure that partially gives the same effect is to cover one-half of the film in the cassette with a piece of the black paper that comes around the film. This side of the cassette should be placed under the normal lung. The black paper will prevent the fluorescence of one of the screens from reaching the film thus tending to equalize the exposure.

A Potter-Bucky diaphragm is not usually used for exposure of films of the thoracic structures. Sometimes, however, exposures with a diaphragm are made to increase detail in dense areas of involvement in the lungs or in the thoracic wall.

BRONCHOGRAPHY.

By bronchography is meant the roentgenological examination for bronchiectasis, lung abscess, tumors, and other conditions after the bronchial tree has been rendered visible by the instillation of some radiopaque material. Most often some stable form of iodine or other halogen in oil is used for this purpose. There are several ways of introducing the opaque oil into the bronchial tree. In the supraglottic method the oil is dropped onto the back of the tongue and permitted to run down into the larynx and the lower air passages. A catheter may be introduced into the glottis or even into the trachea and the oil injected through it; the oil may be injected through the cricothyroid membrane, or it may be injected during a bronchoscopic examination.

The supraglottic method probably is the most often used. The swallowing reflex is first abolished by anesthetizing the back of the tongue and the pharynx. This is done by spraying the throat with 2 per cent cocaine solution, and then swabbing the tongue, faucial

pillars, and pharynx with 10 per cent cocaine solution. The anesthesia is complete when the patient is unable to swallow. By grasping the tongue between the thumb and the index finger of the left hand, with a towel or piece of gauze, and pulling it forward, any solution dropped onto the back of the tongue will run into the upper aperture of the larynx and into the trachea and bronchi.

Farinas has suggested that the opaque oil (Merck's 40 per cent neo-iodipin) be introduced by vaporization. After anesthetizing the pharynx, larynx, and trachea, the tip of an atomizer is placed with its curved end behind the epiglottis and the oil is vaporized by compressed air, the patient breathing deeply in the meantime. Five cubic centimeters are used for the larynx and upper part of the trachea and 15 cubic centimeters for the trachea, larger bronchi, and lower pulmonary lobes.

To prevent coughing it may be advisable first to introduce 1 cubic centimeter of 10 per cent cocaine solution warmed to body temperature. The opaque oil is then dropped onto the back of the tongue by using a syringe fitted with a curved cannula, the curve being such that the oil will reach the tongue near the upper aspect of the epiglottis. The oil should be warmed to body temperature. The patient should be instructed to breathe quietly, to refrain from trying to swallow, and to keep from coughing during the instillation and during the examination.

The posture of the patient will largely determine the part of the bronchial tree that is filled. If the patient leans to the left, most of the oil will pass into the lower left bronchi; if to the right, the lower right bronchi will be filled. If the oil is to reach the upper lobe bronchi, the patient must be placed in the lateral position and tilted head downward as soon as the injection has been completed.

The roentgenographic examination does not differ materially from any other examination of the chest. Postero-anterior, antero-posterior, and lateral exposures should be made, either single or stereoscopic. If the lowermost bronchi are being examined, those that extend into the lower posterior part of the lung behind the highest part of the diaphragm, the intensity of the exposure must be greater than for bronchi above the diaphragm. Films of this region will sometimes be improved by using a Potter-Bucky diaphragm, or a wafer grid.

As short a time as possible should elapse between the injection and the examination. This prevents the oil from reaching the alveoli of the lungs, and it minimizes the danger of having the patient cough up the oil. The best procedure is to prepare for the examination and do the instillation in the *x*-ray room; then the examination can be made as soon as the preparation is completed.

After the examination is finished, the patient is encouraged to cough up the oil. It is an advantage to institute postural drainage to assist in the removal of the oil. Place the patient face down on tilting table and tilt the table until the patient, head down, is at an angle of 25 to 30 degrees.

THE HEART AND AORTA.

Roentgenological examinations of the heart should be, like those of the lungs, both fluoroscopic and roentgenographic. With the patient erect, either standing or sitting on a high stool, and with the fluoroscopic screen in front of the chest, a fluoroscopic examination should be made. The heart should first be studied in the direct postero-anterior projection. The size of the shadow as a whole and of the different chambers, the shape, the rate and amplitude of the contractions, the rhythm, the sequence of the contractions of the atria and ventricles, and the movements on respiration can be determined. By closing the diaphragms to the smallest opening, it sometimes is possible to see calcification in the valves of the heart and the coronary arteries.

The patient should then be examined in the right anterior oblique position by turning the patient to the left with the right side of the chest against the fluoroscopic screen. In this position the arch of the aorta will be seen. When slight rotation of the patient has determined the narrowest shadow, the ascending aorta will be seen in its exact size, plus the distortion due to divergence of the rays. In this position the posterior border of the aorta and heart is outlined in the clear space in front of the spine. If observed during swallowing of a mouthful of barium mixture, the posterior border of the aorta and heart can be clearly outlined. Enlargements of the left atrium often are most clearly shown in this examination.

By turning the patient to the left oblique position the aortic arch is seen in profile. In many instances information as to its size, curvature, length, and density can be obtained. In this position the ventricles and apical portion of the heart can be seen to best advantage and examined for shape, size, and amplitude of contractions.

During any part of a fluoroscopic examination, if the screen be fixed in front of the patient, a tracing may be made of any or all of the fluoroscopic image, of the respiratory movements of the heart, etc. The glass of the screen may be covered with a piece of cleaned film base and the tracing made with a wax pencil. For a permanent record the tracing may be transferred to a piece of paper (Fig. 171).

By the use of fluoroscopes in which the x-ray tubes may be moved

independently of the patients and the screens, and by means of attachments for other fluoroscopes, orthodiagraphic tracings of the cardiac outlines giving accurate dimensions of the heart shadow can be made. Orthodiagrams serve the same purpose as teleoroentgenograms in determining cardiac size and shape (Fig. 172). Of course such work should be undertaken only by those who are familiar with the normal and abnormal appearance of these structures and who have acquired skill by study and practice in this kind

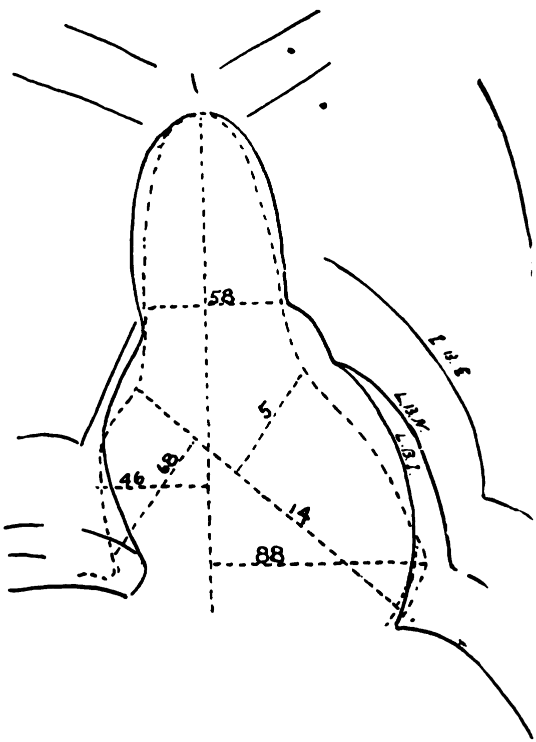

FIG. 171.—Tracing of the heart showing the cardiac size and shape and the normal respiratory excursion of the heart and diaphragm during quiet and forced respiration, with the patient standing. (Holmes and Ruggles.)

of an examination; ordinarily it is work not belonging within the province of a technician.

Roentgenography of the heart is limited in its usefulness to determining the size and shape of the heart from measurements of the cardiac shadow. If films of the thorax in the postero-anterior direction be exposed with an anode-film distance of 6 feet or more, with the patient standing or sitting, teleoroentgenograms will be made which show the size of the cardiac shadow with but little distortion. From these may be obtained the measurements of the

different diameters and of the total area. From a comparison of these with figures given in tables of known normals, the presence or absence of cardiac enlargement may be determined. If changes in shape also should be present, these can be detected; and when characteristic of some definite organic lesion, they assist in making diagnoses of cardiac diseases. In studying cardiac shape, the variations incident to variations in body habitus should be remembered.

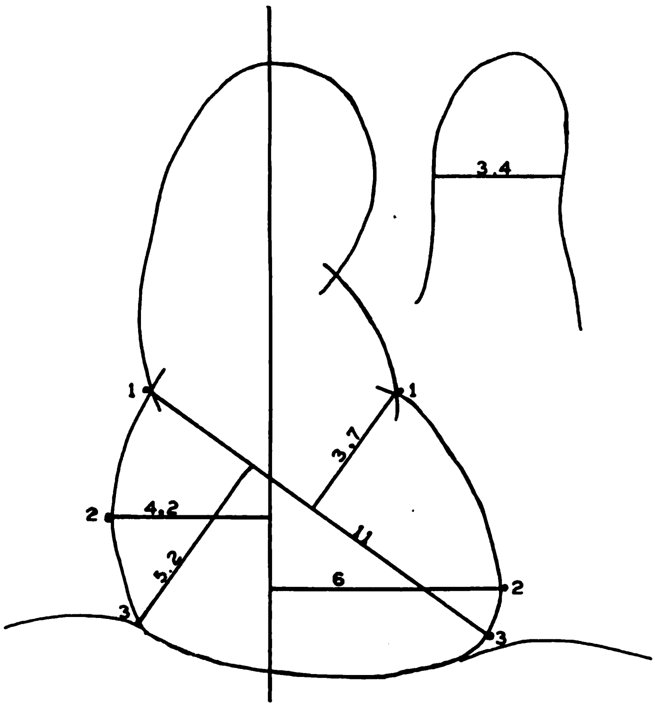

FIG. 172.—Orthodiagram of the cardiac shadow made with an attachment for a vertical fluoroscope.

During the fluoroscopic examination a mark may be placed on the patient's body opposite the center of the cardiac shadow. This serves as a localization point for determining the height of the x-ray tube and the location of the central ray in making a teleoroentgenogram. For the film, the patient is placed in front of a vertical plate changer or other cassette-holding device in much the same position as for a film of the lungs. The rays should pass through the heart at right angles to the transverse plane of the body. It is important to have the patient properly positioned, for a slight rotation of the body to one side or the other will considerably distort the cardiac shadow.

If one wishes a film on which the heart shadow is shown at its maximum, the exposure should be long enough for the heart to complete a cardiac cycle (one second); then the image will be shown at diastole. For sharply defined cardiac borders the exposure must not be longer than one-twentieth second. In such exposures it is not necessary for the patient to suspend respiration. For an undistorted image of the heart, respiration should be shallow and regular. If the film be exposed at the end of full inspiration, like those taken to examine the lungs, the heart will be pulled downward by the movement of the diaphragm and the shadow will be elongated and narrowed. Apparatus has been developed for synchronizing exposures with certain phases of the cardiac cycle—at the end of diastole or at the end of systole, for example. Such apparatus is not in general use. If one wishes to attempt such a procedure, if the *x*-ray switch be closed at the maximum impulse of the pulse at the wrist, the heart will nearly always be near the same phase in the cycle.

When the film is dry, three points are marked on each side of the cardiac outline (Figs. 172 and 173). On the right side these are: (1) At the junction of the shadow of the right auricle with that of the great vessels. (2) The point of the heart shadow that reaches farthest to the right. (3) The junction of the heart shadow with that of the diaphragm. On the left side these are: (1) The junction of the left auricle with that of the left ventricle. (2) The point of the heart shadow farthest to the left. (3) The apex of the heart. A line drawn through the middle of the vertebral column is used as a median line. With these points as guides the various measurements are made. From the median line at right angles to the points farthest to the right and to the left gives the transverse diameter. From the highest point on the right to the apex constitutes the longitudinal diameter; while the sum of measurements at right angles from the longitudinal diameter to the highest point on the left and lowest point on the right gives the diameter of the base. For comparison with those determined during the examination, the normal measurements may be obtained from Claytor and Merrill or from any of the editions of Holmes and Ruggles.

A different method of determining heart size was adopted by the cardiovascular service of the army during the World War. It was based on the work of Bardeen, who made measurements of the total area of the cardiac silhouette. This method is given in the United States Army X-ray Manual, first edition, page 412. The total area of the shadow is determined from a teleoroentgenogram made in the manner described above, using a distance of 6 feet, with the sternum flat against the cassette, and the central rays directed through the ninth thoracic vertebra. The heart outline

is completed by extending the line for the right and left margins across the base of the great vessels, around the apex, and across the diaphragm (Fig. 173). The area thus outlined is measured with a perimeter or by means of an area ruled in square centimeters. If the latter be made on a piece of cleaned film, it may be placed over

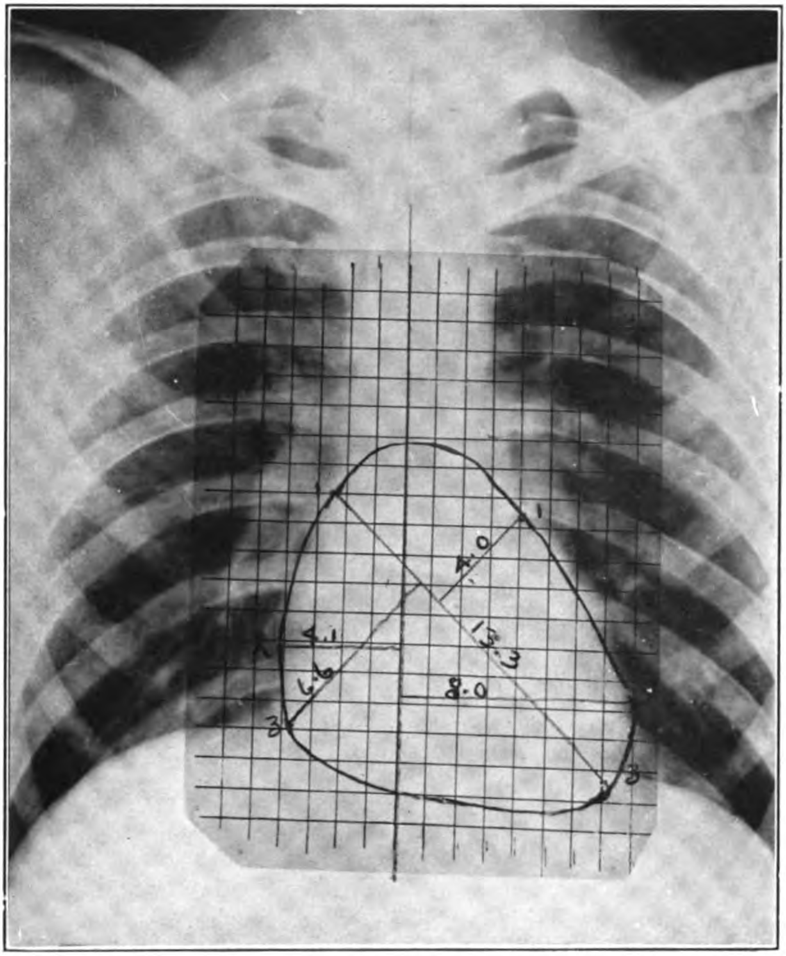

FIG. 173.—Teleoroentgenogram of the heart showing the method of making measurements of the diameters and of the total area of the cardiac shadow by means of a cleaned film ruled in square centimeters.

the film and the heart area determined by counting the whole squares and estimating the fractions. The variations from normal, if any, are determined from the tables for normals of individuals of different height and weight prepared by Bardeen.

In a newer method of roentgenological study of the heart and

aorta, teleoroentgenograms of the heart are made in the left oblique position. This was originated by O'Kane, Andrews, and Warren, and has been extensively used by Fray. The technique as given by Fray is as follows: Fluoroscopy is used in determining the exact position for the exposure of the film. With the patient behind the fluoroscopic screen in the erect position and turned toward the right, the body is slowly rotated until the position that gives the smallest horizontal diameter of the heart shadow is determined. This is usually with the coronal plane of the body forming an angle of 40 to 45 degrees with the fluoroscopic screen. This position is duplicated during the exposure of the film, the film replacing the screen

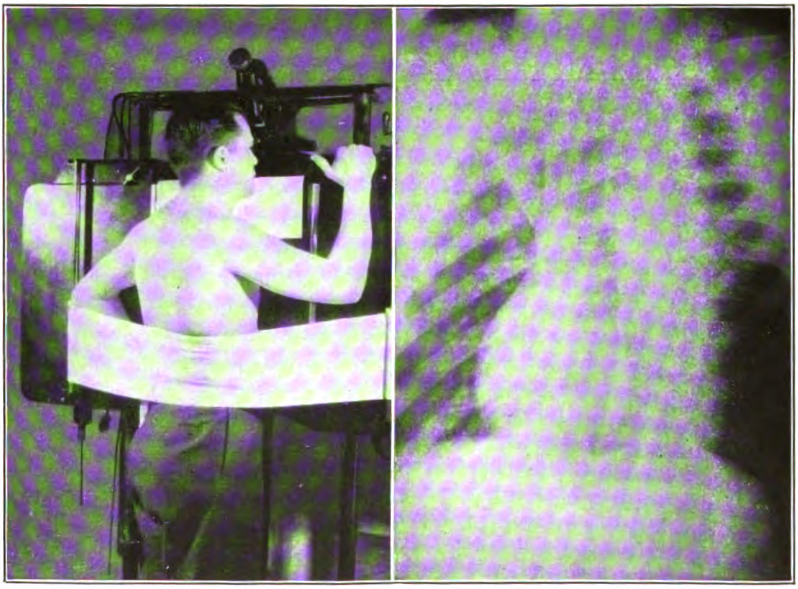

Fig. 174.—Left anterior oblique exposure of the heart and aorta.

in front of the patient's chest. In position for the exposure, the left shoulder presses against the cassette holder with the palm of the left hand against the corresponding hip. The right shoulder is rotated forward; the right upper extremity is elevated and resting on the cassette holder (Fig. 174). Respiration is suspended at the end of a moderately full inspiration. To show the size of the heart in diastole, the exposure should be longer than a full cardiac cycle.

The aorta may be studied both with the fluoroscope and on films. In the postero-anterior direction the ascending aorta overlaps to a variable extent the beginning of the descending thoracic aorta. The diameter of the aortic arch is best seen in right oblique views of the chest. The ascending aorta and the arch are best seen in left

oblique views. No particular position of the patient for roentgenograms of the aorta will be correct in all instances. A good procedure is to determine by fluoroscopic examination the position of the patient that gives the desired view of the aorta and then to place the patient in this position for the exposure of the film. By arranging the patient before a vertically-placed film in the same position that he occupied behind the screen of the fluoroscope, similar images will be obtained.

THE THYMUS.

In infants and young children the thymus frequently is enlarged, causing interference with respiration and swallowing. Cases of sudden death of children during anesthesia, usually for the removal

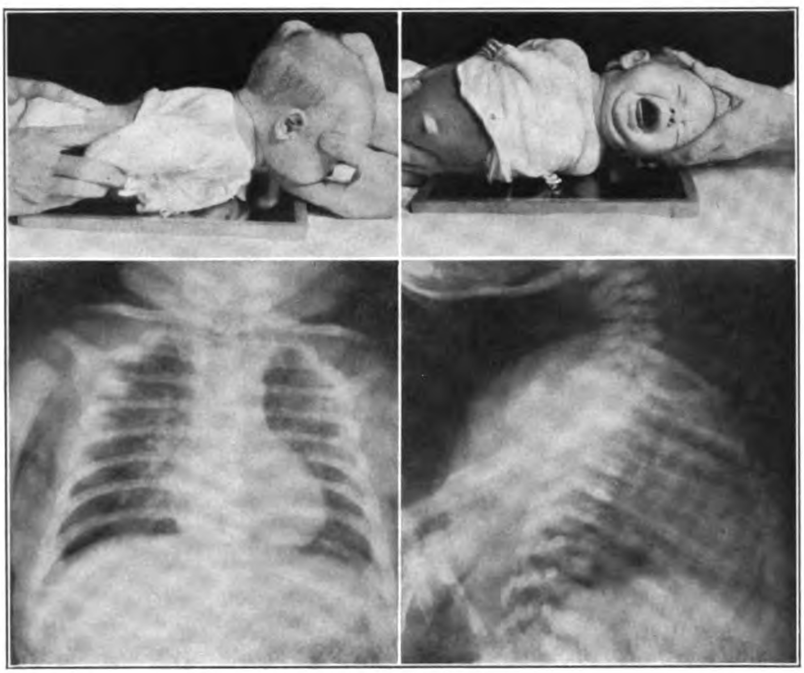

FIG. 175.—Postero-anterior and lateral exposures of the thymus gland of an infant.

of tonsils and adenoids, have been attributed to an enlarged thymus. Roentgenograms are required for detecting this condition. These may be made in the supine or prone and in the lateral positions. For showing the transverse dimensions of the thymus, the prone position is the better one. The antero-posterior dimension and the presence or absence of pressure on the trachea are determined from the lateral film. Since these patients are not coöperative and often

are intractable, considerable persistence and patience, even to the making of several exposures, may be required before satisfactory films are obtained.

The patient should be stripped and placed as nearly as possible in the prone position with the chest on an 8- by 10-inch cassette (Fig. 175). It usually is necessary to hold the arms, legs, and head. Care should be exercised to have the chest and head in a symmetrical position, for direct postero-anterior views without rotation are the most satisfactory. Since when the child is crying the thymus is larger, probably from engorgement, the louder the child cries the better. Each cry is followed by a deep inspiration. At the beginning or ending of each cry there is a momentary period during which the breath is held. This is long enough to make a one-tenth-second exposure. A distance of at least 35 inches should be used.

For films in the lateral position the child is held with the right or left side against the cassette. Both arms must be held behind the baby's back and the head must be supported. The head, neck, and thorax must be in a symmetrical posture and to be satisfactory the exposure must be directly lateral or transverse in direction (Fig. 175).

Remer and Belden obtain postero-anterior views by having the child held erect by the nurse with the thumbs holding the cassette and the fingers holding the child's shoulders against the cassette. They emphasize the importance of making the exposures during crying, and make two views, one at the end of inspiration and one at the end of expiration.

The examination of the esophagus, a part of the alimentary canal, will be discussed in the next chapter.

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CHAPTER XIX.

THE GASTROINTESTINAL TRACT.

THE ABDOMEN AND THE GASTROINTESTINAL TRACT.

THE abdomen contains all of the alimentary canal except the thoracic portion of the esophagus, and it contains the greater portion of the urinary tract as well as other important structures. All portions of the alimentary canal, some of its accessory organs, and the urinary tract can be individually examined. Sometimes it is advisable to make an examination of the abdomen as a whole. In this chapter will be considered the examination of the general abdominal cavity and particularly the different portions of the alimentary canal. The urinary tract will be considered in the following chapter.

Before undertaking an examination of any of the viscera, it is advisable and often important to expose a film of the whole abdomen. This may be made either in the prone or the supine position; the supine film may give more information than the one made in the prone posture. To include all of the abdominal structures the 14- by 17-inch film with its long axis parallel with the mid-plane of the abdomen must be used.

The examination of a film exposed in this manner may give important diagnostic information. It should be examined for the size, shape, and position of the kidneys; for calcifications within the urinary tract, the pancreas, the gall bladder, and the abdominal lymph nodes; for the size and shape of the liver, for abnormal distribution of gas in the intestinal tract, for tumor masses within the abdomen, for disease processes involving the lower two or three thoracic and all the lumbar vertebræ, etc.

Occasionally an examination of the abdomen without opaque material is made for a specific purpose. Evidences of intestinal obstruction, paralytic ileus, and rupture of hollow abdominal viscera may be found in this way. Films for signs of intestinal obstruction are made in both the erect and prone positions. A film in the erect position shows the abnormal distention of the small intestine or colon with gas, and in addition it is particularly valuable in showing air-fluid levels in the intestine. The film in the prone position, preferably exposed using a Potter-Bucky diaphragm, shows the distribution of the gas in the intestinal tract and is particularly valuable in showing the so-called ladder pattern in a distended

small bowel. If the patient is too ill to assume the erect posture, much the same information can be secured from a postero-anterior film exposed with the patient in the lateral recumbent position, with a pillow under the abdomen, with the film vertical in front of the abdomen, and with the rays directed horizontally through the back (see Fig. 170). Any air-fluid levels that may be present on such a film will be horizontal instead of transverse in direction.

If the symptoms of the patient suggest a ruptured hollow abdominal viscus, a postero-anterior film may be taken either in the erect or the lateral recumbent position. On the first of these there may be an accumulation of free gas or air in the abdomen. Most often this is found under the diaphragm separating it from the liver on the right and from the fundus of the stomach on the left side. A pocket of gas may be found under the liver. Such accumulations most often are important supportive evidence in a clinical diagnosis of a ruptured peptic ulcer, but they may be due to some other abdominal condition. A free pocket of air or gas localized in the lower right portion of the abdomen may indicate a localized peritonitis from a ruptured appendix. In subphrenic and subhepatic abscesses an air-fluid level under the diaphragm or under the liver may be an important diagnostic finding. Patients afflicted with these conditions are best examined in the left lateral recumbent position which will give a horizontal air-fluid level on the film.

Under the heading of gastrointestinal tract will be considered all parts of the alimentary canal—the esophagus, stomach, small and large intestine, and appendix—and the gall bladder and liver.

Except the esophagus, all of these structures are contained within the abdomen, a part of the body the characteristics of which depend, possibly even more than those of the thorax, on the body form or habitus of the individual. Upon habitus also depend variations in the shape, position, size, tonus, and activity of the different parts of the alimentary canal which often are pronounced and with which the technician should be familiar.

Referring again to Mills' two dominant types, the hypersthenic and asthenic, marked differences in the abdomen are found in these two forms (Figs. 176 and 177). Persons of the hypersthenic habitus have a long abdomen with the greater abdominal capacity in the upper part, the pelvis being relatively small and occupied by extraperitoneal fat. In general in this type the greater upper abdominal capacity, with the large amount of omental and extraperitoneal fat and the greater tonus of the anterior abdominal muscles, is responsible for a high position of all abdominal parts of the alimentary canal.

Contrasted with this, individuals of the asthenic habitus have a

short abdomen with the greater abdominal capacity in the lower part, that of the upper part being relatively small. The usual

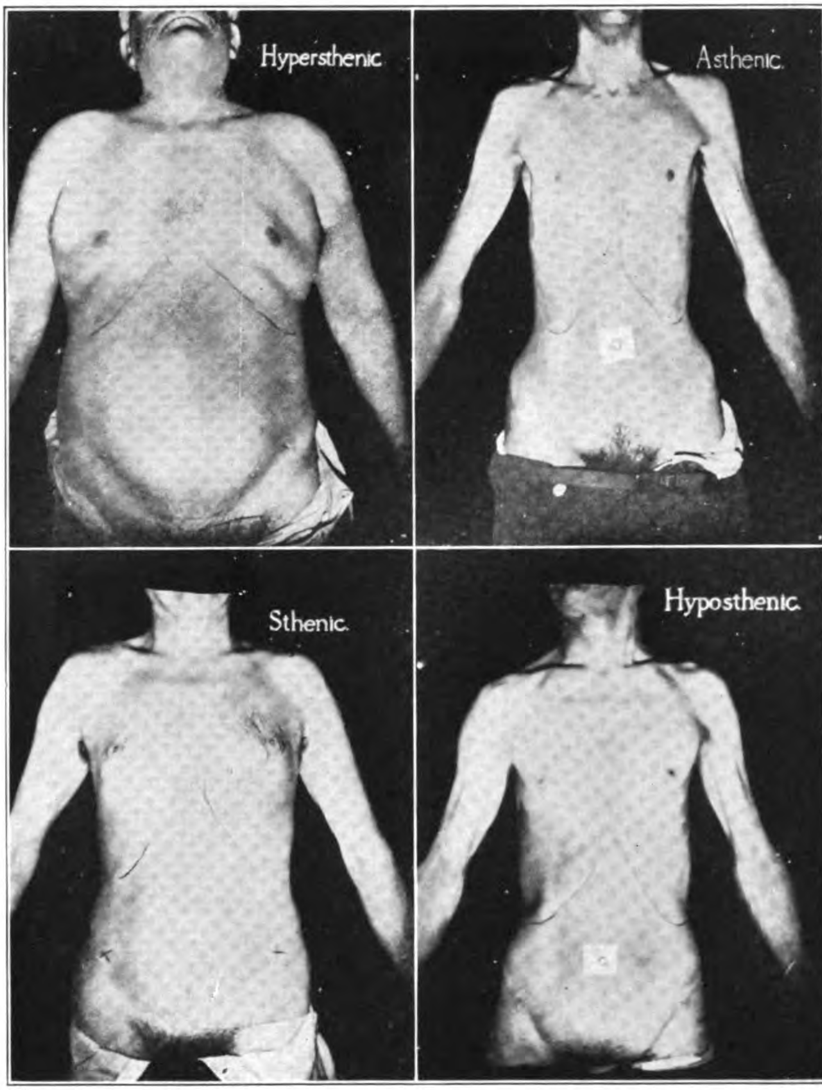

Fig. 176.—Photographs of types of bodily habitus. (After Mills. Reproduced through the courtesy of the American Journal of Roentgenology and Radium Therapy.)

absence of abdominal fat and the lessened tonus of the abdominal muscles with the greater capacity in the lower part are responsible for the relatively low position of parts of the alimentary tract.

As stated in the discussion of the effects of habitus on the thoracic viscera, only a small percentage of individuals belong to these two extreme types; others present some intermediate form of which all

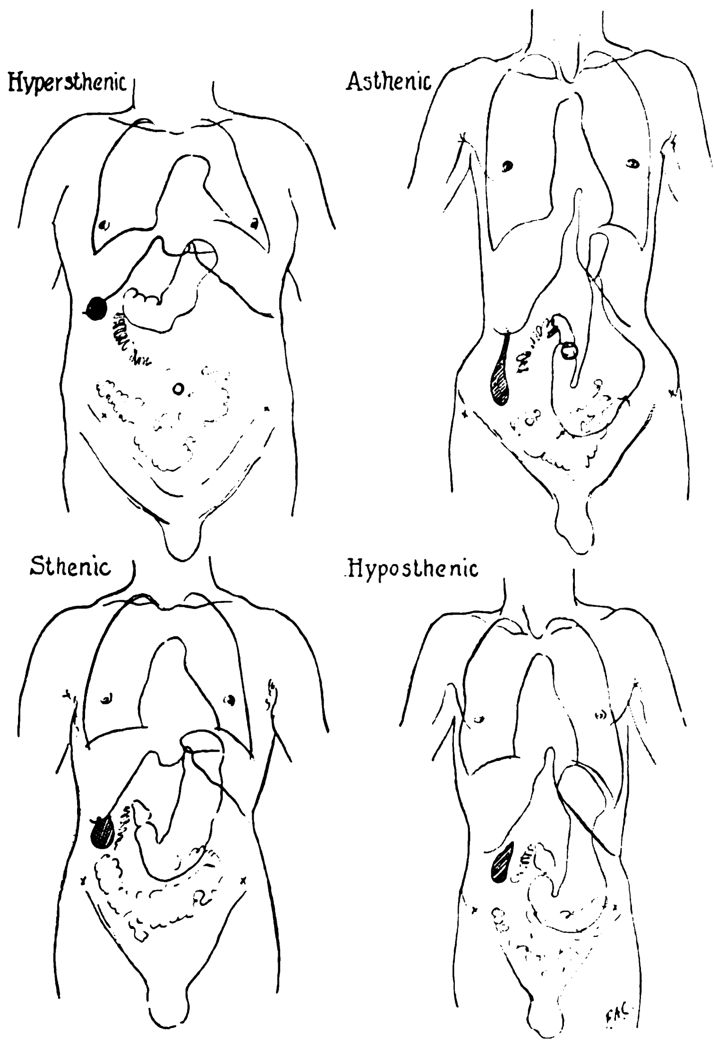

FIG. 177.—Diagrammatic representation of bodily habitus, including form and position of some of the thoracic and abdominal viscera. (Modified from Mills and reproduced through the courtesy of the American Journal of Roentgenology and Radium Therapy.)

possible gradations are encountered. Corresponding closely to the differences in habitus are equal and as important normal variations in the form, position, tonus, and motility of the abdominal parts of the alimentary canal.

For example, the stomach of a person of the hypersthenic habitus is steerhorn shaped and high in the abdomen (Figs. 176 and 177). The fundic portion, located under the left arch of the diaphragm, is the widest part. From the fundus the body and pyloric portion extend obliquely downward and toward the right across the upper part of the abdomen above the umbilicus. The pylorus is the most dependent portion, the duodenal cap being located at the level of the pyloric sphincter or slightly lower. In a stomach of this form tonus is good and peristalsis active, as a result of which emptying is rapid.

When filled, the stomach of a person of asthenic habitus, to correspond to the body form of the individual is of a fishhook shape with the most dependent portion of the greater curvature below the umbilicus (Fig. 177). The fundic portion is located in the left arch of the diaphragm, from which the stomach passes vertically downward for a variable distance in the left side of the abdomen to curve to the right across the vertebral column and finally to pass upward to terminate in the pylorus on the right side of the second, third, or fourth lumbar vertebra. The pylorus is always higher than the most dependent portion of the lesser curvature. The tonus of the musculature of such a stomach is diminished; active peristalsis is limited to the prepyloric portion, the waves being infrequent and slowly moving; the emptying is slow.

Since most persons are of intermediate habitus, the stomach correspondingly varies between the hypersthenic and asthenic extremes. Moody, Van Nuys, and Chamberlain have made a careful examination of the position of the stomach in 1000 healthy young American adults, an equal number of males and females, none of whom gave a history of digestive trouble. The roentgenograms were made with the subjects in the erect position and the stomach filled with a barium meal weighing slightly more than $1\frac{1}{2}$ pounds. A line connecting the highest points of the iliac crests, which is slightly below the usual position of the umbilicus, was used as a level from which to measure the position of the viscera. In 25 per cent of the males they found that the greater curvature of the filled stomach was located above the interiliac line, in 51.8 per cent in the first 2 inches below the line, and in 23.2 per cent still lower in the abdomen. In the female subjects the stomachs were somewhat lower; 11.6 per cent were located above, 45 per cent in the first 2 inches below, and 43.4 per cent more than 2 inches below the interiliac line. These figures give a very good idea of the position and consequently the shape of the filled stomach in both males and females when examined in the erect position.

The position of the duodenum varies in much the same manner

as does that of the stomach. The first portion, called by roentgenologists the duodenal cap, which is functionally and developmentally a part of the stomach, varies in position depending on the type and location of the stomach. Its range of positions is along the anterior aspect or to the right, occasionally to the left, of the first, second, third, and fourth lumbar vertebræ; it is highest with stomachs of the steerhorn shape in the hypersthenic and lowest with the so-called atonic stomachs in the asthenic (Fig. 178). The duodeno-jejunal flexure, supported by the suspensory muscle of the duodenum (ligament of Treitz), is as constant in its position on the left of the second lumbar vertebra as any part of the intestinal tract. In a person with a low stomach the flexure often is seen at a level higher

FIG. 178.—Variations in the shape and position of the filled stomach as shown on films exposed in the prone position, depending largely on variations in bodily habitus. The upper left figure is reduced somewhat more than the others; the reduction in the size of the others is uniform. The position of the umbilicus is indicated by a black or white spot.

than the lesser curvature. With one end of the duodenum relatively constant in position and the other end variable, the duodenum presents a variety of different shapes and positions. The shape usually is like the letter C, V, or U with the opening directed upward and toward the left.

As a rule, from the duodeno-jejunal flexure the coils of small intestine extend downward in the left side of the abdomen, sometimes across the midline, and a few of the coils may reach into the lesser pelvis. From the lower part of the left side of the abdomen the coils extend across the vertebræ to the right of the umbilicus. They then pass into the right iliac fossa and from there into the lesser pelvis, from which the last coil of the ileum extends upward to terminate at the ileocecal junction (Fig. 186).

Mills described the large intestine of hypersthenic individuals as being short and high in position (Fig. 187). The cecum is out of the iliac basin; the transverse colon is truly transverse and above the umbilicus; the descending colon is longer and straighter than in other types. In asthenic individuals the colon is lower and longer than in other forms. The cecum is located in the small pelvis and is quite capacious. The transverse colon descends into the pelvis. The hepatic flexure often is no higher than the highest point of the right iliac crest, nor is the splenic flexure always as high as the spleen. The latter flexure, however, usually is the most constantly located portion of the large intestine.

Moody, Chamberlain, and Van Nuys made a study of the position of the large intestine in 300 healthy males and in a similar number of females. With the subjects in the anatomical position, in 60 per cent of males and 63 per cent of females they found that the cecum was in the cavity of the true pelvis, and that the transverse colon varied much in shape and position. They found that the transverse colon may be a shallow loop, U- or V-shaped, with equal or unequal limbs, with the apex on the right or the left, or in any intermediate position. Often the right or left portions lie over the ascending or descending colon so that their images are superimposed on x-ray films. In the erect posture they found that in males the most dependent portion of the transverse colon varies from a position 1 centimeter (0.4 inch) above the interiliac line to a position 17.5 centimeters (7 inches) below the line; and in females from the same level above the 18.5 centimeters (7.4 inches) below the line.

ROENTGENOLOGIC EXAMINATION.

Roentgenologic examination is one of the few and by far the most useful of the direct methods of examining the gastrointestinal tract for evidences of disease. Since it is a method of visual study of images on the fluorescent screen or on films, it follows that most conditions which can be detected by it are macroscopic and of an organic nature. Those functional disturbances which produce abnormalities in the movements of the viscera themselves or of the contents through the stomach and intestine, or which, by spasm or otherwise, produce variations in outline or shape also often can be detected. Holmes and Ruggles say that in diseases of the alimentary tract the diagnoses of the average roentgenologist are correct in about 80 per cent of cases, and that a skillful roentgenologist, working under most favorable circumstances, is correct in from 90 to 95 per cent, a statement that shows the importance of x-ray examinations as a diagnostic method.

All examinations for the purpose of seeking pathological changes in the gastrointestinal tract, of which the gall bladder and liver may be considered a part, should follow a certain established routine. Only in this way will the different parts be given consideration and sufficient evidence collected to make a diagnosis of the patient's ailments. When the patient's symptoms are at all vague, not pointing directly to some particular condition, most roentgenologists will agree that the examination should include the entire tract; conclusions from incomplete are more apt to be incorrect than those from complete examinations. In time and materials required, in meticulous attention to details, in the painstaking collection of abnormal findings, and in the final correlation of clinical and x-ray evidences of disease, the roentgenologic examinations of the gastrointestinal tract present more difficulties than most others the roentgenologist is called upon to make.

Any of several plans for the examination of the gastrointestinal tract may be adopted. This should be the basis for all examinations, but the plan that is used should be sufficiently flexible to allow for variations in the established procedure. The gall bladder should first be examined. When this has been done, the study of the alimentary canal may be begun, or the two may be carried on simultaneously. Two general types of examinations have long been used in examining the stomach and intestinal tract. These are called the single- and the double-meal methods. When the single-meal method is used, the patient presents himself at the x-ray laboratory in the forenoon with the stomach empty. A barium meal is administered and the first examination made. Routinely this is followed by a second examination, usually at the end of six hours, the patient not eating in the interval. At this time the emptying of the stomach should be completed and the barium should be in the terminal ileum and in the proximal portion of the colon. The progress of the meal through the intestine is observed, and the structures in the right iliac region are examined. The six-hour interval should not be too rigidly observed. Often one or more examinations at shorter intervals may be advisable. This is particularly true if any examination of the small intestine is to be made.

In the double-meal method of examination the patient is given a preparation of barium sulphate to ingest at a specified time in the morning, or is given a quantity of barium sulphate to take as a part of breakfast. The patient refrains from eating and presents himself at the x-ray laboratory at a certain time, usually six hours later. At this time the second meal is given and the stomach, duodenum, and upper part of the small intestine are examined as well as those structures visualized by the barium taken at the first meal.

The double-meal method has the advantage of combining two examinations in one, with one visit to the laboratory. It is not as flexible as the single-meal method, interum examinations are impossible, and sometimes barium in the transverse portion of the colon may interfere with a thorough examination of the stomach, the duodenum, or the upper jejunum. It does not provide for any examination of the small intestine.

The next examination should be made after an interval of approximately twenty-four hours to determine the rate of passage of the meal through the large intestine and to look for abnormalities. The patient should be instructed to take no laxatives nor enemas between the first and twenty-fourth-hour observations. If the time of complete emptying of the colon is to be determined, studies after twenty-four hours should be made to suit the individual case. The examination is completed by administering a barium enema filling the colon completely. If a careful search is to be made for filling defects and other organic changes, the colon must be emptied of the ingested barium. This can be done by having the patient take a mild laxative the night preceding the examination, to be followed on the morning of the next day by a cleansing enema of soapsuds or lukewarm water. If the colon examination is to be made for redundancies and the condition of the musculature, etc., the barium enema may be given following the twenty-fourth-hour meal examination. The barium in the intestinal contents usually will be more concentrated than that in the enema so that the filling by the two portions can be distinguished. However, this does not detract from the results.

In the following sections each part of the examination is considered as a unit. It must be remembered, however, that each is only a part of a complete examination.

THE GALL BLADDER.

The gall bladder frequently is the seat of infection and often contains stones. Either condition may produce direct or reflex symptoms in the upper part of the abdomen. Since such symptoms so often are reflex and of a vague and indefinite nature, any method of examination that materially assists in detecting the presence of gall-bladder disease is of considerable value. Of these *x*-ray examination undoubtedly is the most reliable.

Preceding and following the development of cholecystography, *x*-ray examination of the gall bladder has passed through distinct phases, excellent accounts of which are given by Graham, Cole, Copher and Moore, and by McCoy. While it is true that at an

earlier period gall-bladder examination was attempted by some of the masters of the art working in the larger laboratories, it was not until after the development of double-coated films and intensifying screens of good quality, and probably not until after the publication of the excellent monograph by George and Leonard in 1922, that this method was widely used. At first, attempts were made to show a large percentage of gall stones and as many pathological gall bladders as possible, and a careful study was made of the rest of the alimentary canal, especially the stomach, duodenum, and colon, for adhesions, pressure defects, etc., which were considered as important secondary evidences of gall-bladder disease.

In this phase the greatest importance was placed on roentgenograms of the very best quality. Considerable contrast and a great amount of detail are required to show gall stones, especially those with but little calcium content, and to picture pathological gall bladders. In an examination several films usually were taken with slightly varied exposure factors in an attempt to find the combination that gave the best film. During this phase the advances made in roentgenography of the gall bladder are just as important today; for, if the gall bladder does not fill by cholecystography, films of the finest quality will be more likely than others to show gall stones, thus increasing the percentage of correct findings.

The last phase in the examination of the gall bladder began in 1924 following the origination of cholecystography by Graham and Cole. These investigators made use of the facts that one of the chief functions of the gall bladder is the concentration of the bile as it is received from the liver and that certain dye preparations of the phthalein series are excreted from the blood by the liver as constituents of the bile. By using dye preparations containing bromine and iodine, they found that, when concentrated in the gall bladder, these substances rendered the bile sufficiently dense to Roentgen-rays that a distinct shadow of the normal gall bladder could be obtained on roentgenograms. To this has been added the study of the ability of the gall bladder to contract and empty itself after a meal rich in fat has been ingested. Cholecystography is then really a test of gall bladder function. If the gall bladder concentrates the bile, changes its shape, and empties itself, and there are no stones nor tumors present, it is considered normal. Experience has shown that a gall bladder that does not give a normal response is diseased. Thus the test becomes of clinical value.

The first preparation used for cholecystography was sodium tetrabromphenolphthalein. Soon this was replaced by sodium tetraiodophenolphthalein as being less toxic and requiring a smaller

quantity. To these has been added sodium phenoltetraiodophthalein, following an injection of which it is possible to do both an *x*-ray examination of the gall bladder and a liver function test. Tetraiodophenolphthalein may be given by mouth or intravenously; phenoltetraiodophthalein always is given intravenously. The pioneer work in cholecystography was done by the intravenous method of administration, and the originators of the test continue to use this method. However, tetraiodophenolphthalein can be given by mouth with good results. The intravenous method of administration requires careful attention to numerous details of sterilization and injection, and it has been known to cause serious reactions. On the other hand, giving the opaque dye by mouth may cause nausea, vomiting, and diarrhea, and there has been a fear that incomplete absorption from the intestinal tract may give erroneous results.

When given by mouth, some or all of the sodium tetraiodophenolphthalein may be changed to an acid and rendered insoluble by the hydrochloric acid of the gastric juice. Although this takes place, it is certain that in a majority of normal persons some of the dye passes through the stomach unchanged or the alkaline intestinal juices change enough of it back to the soluble form to fill the gall bladder and make it visible. If taken after the evening meal in plain gelatin capsules in doses of 0.5 gram for each 20 pounds of body weight and the patient placed on the right side to hasten the exit of the capsules from the stomach, a large percentage of normal gall bladders will be visualized the following morning.

Attempts to devise capsules for the dye that are insoluble in the stomach and soluble in the small intestine were unsuccessful and their use abandoned.

More efficient methods of oral administration of tetraiodophenolphthalein were devised by Levyn and Aaron and by Fantus. Levyn and Aaron suggested that 3 grams of the dye be dissolved in an ounce of distilled water and the solution filtered. This was then added to a glass of Welch's grape juice, the mixture well stirred, and drunk. The originators of this method believe that the weak organic acids in the grape juice change the preparation from a sodium salt to an acid which precipitates out as a fine insoluble precipitate. In this form it will pass through the stomach without being affected by the acid of the gastric juice. In the intestine the acid is changed back to a soluble salt which is absorbed.

Fantus suggested that the dye be precipitated from a solution by the addition of carbonated water or by passing a stream of carbon dioxide through it. This colloid precipitate may be stabilized by

the use of very dilute tragacanth mucilage. In this form the preparation may be taken mixed with water. Given in this way, 2 grams of the dye are said to be enough, nausea and vomiting are prevented, and the dye is well absorbed.

Cholecystography may be performed by giving the dye by the intravenous or the oral method. If one wishes to administer it intravenously, probably it would be better to learn the technique first hand by visiting some hospital or clinic where the method is used. Graham, Cole, Copher, and Moore repeatedly have published the details of the methods used by them. In their monograph the technique given, somewhat abbreviated but in almost a direct quotation, is as follows:

With the aid of gentle heating 2.5 grams of phenoltetraiodophthalein are dissolved in 30 cubic centimeters or more of freshly distilled water and the solution filtered through filter paper. If tetraiodophenolphthalein be used, the dose is 3 to 3.5 grams dissolved in 40 cubic centimeters or more of freshly distilled water. Either solution is sterilized by boiling in a water bath for fifteen to twenty minutes, and when cooled is ready for injection. Solutions prepared in this way may be kept from two to three weeks by sealing individual doses in glass ampoules. If a precipitate forms in the ampoules, the solution should be carefully withdrawn with a syringe or refiltered. The injection is made with a syringe and needle between eight and nine o'clock in the morning with the stomach empty and with the patient lying down. The phenoltetraiodophthalein is given in one dose; the tetraiodophenolphthalein in divided doses a half hour apart. Care should be taken to establish a free flow of blood from the vein before injecting the dye. The injection should be followed by the introduction of physiological salt solution to wash out the vein, thereby reducing the possibility of venous thrombosis. The importance of using absolutely clean glassware and freshly distilled water of known purity in preparing and injecting the solutions is strongly emphasized.

Breakfast is omitted on the morning of the injection, and lunch is limited to a carbohydrate liquid intake. The stomach contents may be alkalinized by the administration of frequent doses of sodium bicarbonate by mouth. Roentgenograms are taken in series at four, eight, twenty-four, and thirty-two hours after the injection.

The oral method of administering the sodium salt of tetraiodophenolphthalein has passed through a long developmental period, and the accumulated literature on the subject is voluminous. All methods of oral administration seem to follow much the same general

plan, but there is considerable variation in the details, differences that individual roentgenologists have adopted to suit their convenience in hours of work, class of patients, etc. There does not appear to be any generally accepted, widely adopted, or standardized method of procedure in this examination. The dye preparation is ingested in liquid form. It is dispensed or prescribed as a solution in water to be mixed with grape juice or some other fruit juice or carbonated drink, or as some commercial preparation, all of which basically are the sodium salt of the dye mixed with a fruit acid such as citric or tartaric, to be taken mixed with water. A general method of oral administration is as follows:

The dose is most often 3, 3.5, or 4 grams of the dye. Kirklin routinely uses 4 grams. Feldman believes that this dosage is inadequate and gives 6 grams as a minimum, increasing the amount to as much as 9 grams for obese patients. The dye is dissolved in 30 cubic centimeters (1 ounce) of distilled water and the solution filtered. This solution should be freshly prepared on the day of administration for it often does not keep longer than twenty-four hours.

On the day preceding the examination the noon meal is permitted as usual. The evening meal should be substantial in amount. Kirklin believes that it should be relatively free from fatty foods, such as eggs, cream, butter, etc. Lean meats, vegetables, fruits, and carbohydrate foods should be eaten.

Immediately after the evening meal the dye is mixed with a full glass of grape juice, orange juice, ginger ale, sarsaparilla, or some other carbonated drink. This mixing is important and it should be thorough. Some effervescence and a change in color will ensue. When the mixing is completed, the entire glassful is drunk. After the dye has been taken, water may be had as desired. All foods and laxatives are prohibited. A cup of black coffee or clear tea may be taken at breakfast time the following morning.

Since it is important that patients thoroughly understand the directions for taking the dye, typewritten or printed instructions should accompany the prescription or be given each patient with the bottle of dye. A satisfactory form reads as follows:

"Eat a substantial supper not later than seven o'clock consisting of broiled or roasted lean meat, vegetables, fruits, dry toast or bread without butter, and clear tea or black coffee. Fatty foods, such as eggs, milk or cream, butter, salad dressing, etc., should not be eaten.

"Immediately after supper pour the blue medicine into a glass, fill the glass with grape juice, orange juice, ginger ale, or some other carbonated drink, stir it for one full minute, and drink it all.

"After this do not eat food of any kind nor take any medicine. Water may be had as desired. A cup of coffee with sugar, or clear tea may be had at breakfast time in the morning.

"Come to this office tomorrow morning at ——— o'clock for the x-ray examination."

The reaction following oral administration of gall-bladder dye consists of nausea, vomiting, and diarrhea. Patients frequently are nauseated. Occasionally one will be encountered who vomits after the dye has been taken. If this occurs immediately after the ingestion of the dye, it may interfere with the examination; but if the patient vomits some hours later and the vomitus be clear, usually the examination may proceed as scheduled. Diarrhea is sometimes troublesome. If there be much diarrhea, one is fearful that the dye has been eliminated and not absorbed. One to 2 drams (4 to 8 cubic centimeters) of paregoric may be given half an hour before the dye is ingested. This allays the nausea and vomiting and prevents the diarrhea.

Many alterations in this general method have been advocated, some of which are distinctly advantageous. Oral cholecystography by the administration of two doses of dye has many advocates. On the day before the examination the noon meal is permitted as usual. The first dose of dye, usually 3.5 to 4 grams, is then taken. A fat-free evening meal is eaten, and the second dose of dye is taken soon thereafter. A dose of paregoric half an hour before each of these doses of dye is advisable. The x-ray examination is made at the usual interval after the second dose. The two doses of dye may be given the same evening, the first after the evening meal and the second an hour to two hours later, with the x-ray examination at the usual interval after the second dose. The examination may follow three doses of dye, one given after the evening meal on the first day and the other two given on the second day as suggested above, the examination being made on the third day.

Efforts have been made to shorten the time required for oral cholecystography. It has been suggested that this can be done by the administration of a large amount of carbohydrate in the form of glucose or sugar. Tu-shan and Moore investigated this subject and found that 100 grams of glucose in 180 cubic centimeters of water did reduce the retention of the dye when it was given intravenously and that the patients had less reaction. Friedman and Friedman are convinced that the ingestion of large amounts of sugar helps in the visualization of the gall bladder and reduces the bad effects of the dye when given orally. They recommend the drinking of several cups of tea each containing 2 teaspoonsful of sugar before and after the dye is taken and on the morning of the examination.

They give two doses of dye in the same evening in their subintensive examination, and three doses in their intensified method. While of benefit, apparently the use of glucose and sugar does not appreciably decrease the time required for the examination.

From time to time there have been advocates of the use of a alkali, usually sodium bicarbonate, as an adjunct to oral cholecystography. When the dye was given in capsules, the alkali was given to neutralize the gastric juice and prevent the hydrochloric acid from making the capsules insoluble. Robinson gives sodium bicarbonate to prevent relaxation of the sphincter of the bile duct (Oddi), thus enabling the gall bladder to fill better, and to promote relaxation of the gall bladder, thus aiding in absorption and concentration of the bile. In the usual examination the first dose of 1 dram is given an hour after the dye is taken, with sufficient succeeding doses during the starvation period, usually four in number, to keep the gastric and duodenal contents alkaline. If the patient has a hyperchlorhydria, 1 dram is given on an average of every two hours, or eight doses in fifteen hours. Robinson begins the examination with a fatty meal in the evening to assure complete emptying of the gall bladder, giving a 4-gram dose of dye in grape juice three hours later.

These refinements in the technique of the administration of tetraiodophenolphthalein by the oral method may be briefly summarized. Two or three doses of dye may be given to assure that an adequate amount has been ingested; paregoric in amounts of 1 to 2 drams (6 to 8 cubic centimeters) may be given half an hour before each dose of dye to prevent diarrhea and diminish nausea and vomiting; glucose or sugar may be given in large amounts to diminish reactions and decrease retention of the dye, and sodium bicarbonate may be given in dram doses at intervals to prevent relaxation of the sphincter choledochus and to relax the gall bladder, thus aiding in concentration of the bile in the gall bladder. As many of these as may be desirable may be added to the general method outlined above.

About four hours after the intravenous and twelve hours after the oral administration of the dye, the normal gall bladder is well filled. The first *x*-ray examination may be made at these intervals. If the patient fasts for four hours longer, the normal gall bladder will be slightly smaller and the dye more concentrated. For this reason many examiners make a second examination after such an interval. A part of the normal functional response of the gall bladder in cholecystography is its contraction and emptying. This is brought about by the ingestion of a meal rich in fat. A glass of cream; or two eggs, cooked in any way, a glass of whole milk, and buttered toast make an adequate fatty meal. Proprietary commercial prepa-

rations are also available for this purpose. Films are exposed at intervals after such a meal. The interval of choice seems to be one hour. At this time the normal gall bladder should be about one-fourth its original size. Others that have been suggested are fifteen and thirty minutes in addition to the one-hour interval. At the end of two hours the gall bladder should be almost or completely empty. Satisfactory contraction and emptying is an additional evidence of normal function, and sometimes non-opaque gall stones and small papillomata not visible on films of the fully distended gall bladder may become visible on films of the partly empty viscus.

Whenever an examination of the gall bladder is part of the study of the gastrointestinal tract and is completed before the examination of the stomach and intestines is begun, the total examination requires three or more days. Many patients object to such a prolonged investigations. By combining the two examinations it is possible to shorten the time. After the first films of the gall bladder, the barium meal may be given and the stomach and duodenum examined. The barium meal should not contain anything that will interfere with the succeeding examinations of the gall bladder. The second gall bladder examination may be made after an interval of four hours. Usually at this time the stomach will be empty. The barium may be examined in the intestinal tract, the fat meal then ingested, and the last examination of the gall bladder made.

This method of examination may be objected to because the meal may interfere with the function of the gall bladder and the barium in the stomach, duodenum, or colon may obscure the shadow of the gall bladder on the films taken at the second and third examinations. However, it has the advantages of making possible more than one examination of the gall bladder and requiring no more than two or three days to complete the study of the gall bladder and gastrointestinal tract.

Irrespective of the method of giving, the time of the examination, or whether or not the dye is used, the x-ray examination of the gall bladder is the same. Since it is located in the anterior part of the abdominal cavity near the posterior surface of the anterior abdominal wall, the prone position brings the organ nearer the cassette than any other. The patient should be placed on the table in this position, with the head turned to the right so that the chin is over the right shoulder. The left upper extremity should be along the side of the trunk; the right may be flexed around the head (Fig. 179). The patient should be thoroughly relaxed on the table. To assist in this, Kirklin advises placing a pillow under the ankles so that the weight of the feet is not supported on the toes. A tightly applied compression band should be stretched across the back at the level

of the lower ribs. In all examinations the rays from the tube should be directed perpendicularly to the table top. If any variation from a direct postero-anterior path of the rays be necessary, it should be obtained by turning the patient and not by tilting the tube.

In order that the tube may be properly focused and the cassette correctly placed with the patient prone, the approximate position of the gall bladder with reference to the dorsal surface of the abdomen must be determined. The landmarks by which this must be done are the lower ribs, the spinous processes of the vertebræ, and the posterior part of the crest of the ilium. As they extend downward and lateralward from their vertebral attachments, the eleventh and twelfth ribs usually can be palpated. The location

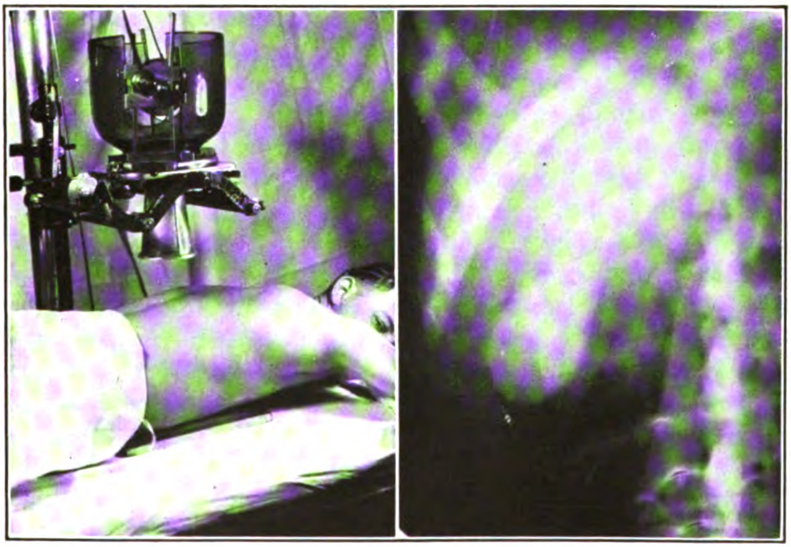

Fig. 179.—Postero-anterior exposure of the gall bladder, patient of average habitus.

of the gall bladder with reference to the ribs varies with the habitus of the patient and the amount of abdominal fat. With a patient of average habitus, approximately intermediate between the hypersthenic and asthenic, on a direct postero-anterior view the gall bladder will appear superimposed by or lying just below the shadow of the twelfth rib. For this habitus, therefore, the central rays from the tube should be centered over the twelfth rib midway between the vertebral column and the lateral margin of the body, and the cassette placed so that this point is over its middle. When so placed, it will be found that the tip of the twelfth rib lies near the junction of the upper three-fourths with the lower fourth of the lateral margin of the cassette (Fig. 179).

For the examination of many patients this position will be correct. For those who approach the hypersthenic habitus or who have a large amount of abdominal fat, the position of the gall bladder will be higher; for those who approach the asthenic habitus or who have lax abdominal walls, the position will be lower. Occasionally, with a patient who is both hypersthenic and corpulent, the gall-bladder shadow will lie high under the ribs, even so high as to be superimposed over the shadow of the ninth intercostal space (Fig. 180). For such patients the tube should be centered over the eleventh rib or tenth intercostal space, and the cassette placed accordingly.

In patients who approach the asthenic habitus, the gall bladder is not only lower in position, but it approaches the midline of the body. For such the tube should be centered over the interval between the twelfth rib and the highest part of the iliac crest and closer to the vertebral column. In examining such patients it often is advisable to place a small sand bag under the right hip bone, thus elevating it from the table. This will turn the body enough to throw the shadow of the gall bladder clear of that of the spine. In rare instances the shadow of the gall bladder may reach over that of the iliac crest into the right iliac fossa.

Some other than the prone position may be used for the examination of the gall bladder. Because occasionally there is layering of the material in the gall bladder and because some non-opaque gall stones may float, films in the erect position may be preferable to those in the prone position. The details of the exposures are the same as for those in the prone posture except that the film is vertical, the patient erect, and the x-rays directed horizontally. On the average the gall bladder will be found slightly lower in the abdomen when the patient is erect. This will not be enough to change materially the details of the exposures.

Films with the patient turned to the left anterior oblique position should sometimes be made. By elevating the right side of the abdomen to an angle of 30 or even 45 degrees, the shadow of the gall bladder may be separated from that of the hepatic flexure of the colon, and better visualization of the gall bladder be obtained. With a patient of the hypersthenic habitus and the gall bladder located high under the liver, films exposed in the right anterior oblique position may displace the gall bladder shadow from under the liver and show it to better advantage.

Occasionally it is necessary to determine whether opaque shadows in the gall bladder region are in the gall bladder or in the right kidney. Films in the supine and right lateral positions are then an advantage. If the shadow be that of a calculus in the gall bladder,

it will be smaller and better defined on the film made in the prone position; if it be that of a calculus in the kidney, the reverse will be true. On the film exposed in the right lateral position the shadow of a urinary tract calculus will be posterior to the vertical line connecting the anterior aspects of the vertebræ, and that of a gall stone will be more anteriorly situated.

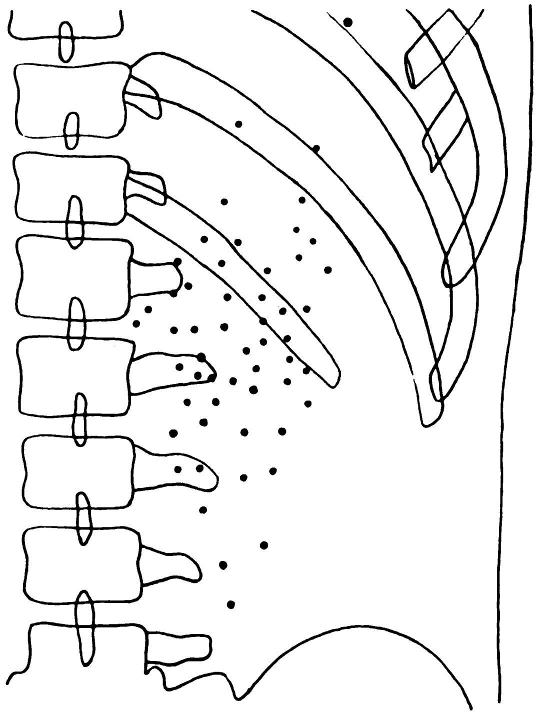

FIG. 180.—The position of the gall bladder as shown on films of 54 unselected patients. The dot represents as nearly as possible the center of the fundus. Most of them are located behind the shadow of the twelfth rib or in the angle formed by the rib and the lateral margin of the vertebral column.

During the exposure of films of the gall bladder respiration must be suspended. This is accomplished best at the end of a full expiration (see page 204). It always is advisable to rehearse the breath-holding sequence before the exposure is made. By doing so the patient will understand just what is expected, and the spoiling of many films by breathing and motion will be prevented.

The best practice in gall-bladder roentgenography is that recommended by George and Leonard in which one or two films are developed and examined immediately after being exposed. If they are not entirely satisfactory, additional films are made. In this way the position of the tube, the cassette, and the patient and the

correctness of the exposure factors can be determined. It may be found that gas and fecal material in the colon obscure the gall-bladder region to such an extent that removal by a cleansing enema either with or without the use of pitressin may be necessary before satisfactory exposures can be obtained (see p. 217).

Films of the highest technical quality must be secured. They should show the eleventh and twelfth ribs, the vertebral column, especially the transverse processes, the lower border of the liver, the edge of the psoas muscle, and the right kidney. The least blurring of any of these structures indicates that immobilization has been unsatisfactory and additional films should be taken.

On the average more satisfactory films can be made by using a Potter-Bucky diaphragm and a cone or diaphragm of the size appropriate for the films being used. The films should show considerable contrast. Those made with a low voltage, high milliamperage, and a short exposure time usually are the best. By careful posing, films of the 8- by 10-inch size can be used for most gall-bladder exposures. For large individuals the next larger film occasionally may be preferable.

CHOLANGIOGRAPHY.

By the injection of opaque material, it is possible under certain conditions to visualize the bile ducts, and through fluoroscopy or exposed films get information that cannot be obtained in any other way. At operation, if bile be drained from the gall bladder and the opaque substance be injected with a syringe and blunt needle, the gall bladder and bile ducts can be filled. During the exposure of films it is necessary for the patient to suspend respiration. This cannot be done with inhalation anesthesia, but it is possible when spinal anesthesia has been used. After operation the opaque material may be injected through a T-tube that has been left in the common bile duct for continuous drainage. It is good practice, and one that is followed in many hospitals, to examine every patient in this way before the T-tube is finally removed. If a biliary fistula develops, the opaque substance may be injected through a small rubber catheter inserted into the opening of the fistula, or even through the barrel of a glass syringe with the tip for the needle inserted into the mouth of the fistula.

Different opaque substances have been used for this purpose. The first examinations of this sort were made with bismuth paste and suspensions of barium. Iodized oil, either full strength or diluted half with sterile olive oil, the different iodine preparations that are used for intravenous urography, thorotrast, and a 12 per

cent solution of sodium iodide are other preparations that have been used. Bismuth and barium probably should not be used because of the difficulty of the elimination of these insoluble substances. Iodized oil preparations are satisfactory, but there is a tendency for some of the oil to separate in droplets, and not give a complete, clearly outlined filling of the ducts. The iodine preparations that are watery solutions, or sodium iodide solutions, are perhaps preferable.

The sequence of events that occur in cholangiography can best be seen if it be possible to watch the injection fluoroscopically with the patient on a horizontal fluoroscopic table. Sterile preparations should be used, sterile precautions should be observed, and the injection warmed to body temperature. Slight pressure is permissible. If the injection be through a T-tube in the common bile duct, this duct will fill, and the opaque material will pass upward and fill the right and left hepatic ducts and some of the larger ducts of the liver. If there be no obstruction and if the sphincter be relaxed, some of the opaque material may be seen to enter the duodenum, and the filling of the bile radicles is not so complete. If the injection be made through a fistula, the fistulous tract first will fill, followed by filling of the ducts. Following the injection films are exposed, either singly or stereoscopically, at intervals of fifteen to thirty minutes. These are examined for stones in the ducts, for strictures of the ducts, etc. If the opaque material passes readily into the duodenum, there is no obstruction. Spasm of the sphincter of the common bile duct (Oddi) may be relaxed by inhalation of amyl nitrite, by the injection of $\frac{1}{100}$ grain of glyceryl trinitrate, or by a $\frac{1}{100}$-grain tablet of nitroglycerine under the tongue. If there be an obstruction, the opaque substance may be retained in the ducts for a considerable period of time. If an obstruction be present in the ampulla or at the duodenal papilla, it may be possible to fill and visualize the main pancreatic duct.

If placed to cover the liver and the upper right quadrant of the abdomen, 10- by 12-inch films are large enough for cholangiograms.

THE LIVER.

Hepatic enlargement is the principal condition for which the liver may be examined by Roentgen-rays. A large film of the upper part of the abdomen will show the upper surface of the liver clearly outlined against the air-filled lung, separated only by the diaphragm. On such films, especially when made with a Potter-Bucky diaphragm, the right border and most of the inferior margin of the right lobe can be identified. Pfahler has made use of this fact and has de-

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scribed a method of determining the size of the liver. He also has collected figures on a series large enough to establish the normal limits of liver dimensions.

The technique described by Pfahler is as follows:

"For these measurements the subject is placed in the supine position upon a Potter-Bucky diaphragm. A 14- by 17-inch film in a double screen cassette is placed crosswise so that the lower border will include about 1 inch of the upper border of the crest of the ilium. This will, in practically all instances, include the entire liver, both kidneys, and the spleen.

"The tube is centered over the ensiform at a target-film distance of 25 inches. It must be admitted that at this distance there will be some inaccuracy due to exaggeration according to the thickness of the patient, but one is surprised at the slight difference that this makes in the figures. A slight allowance will have to be made, therefore, in a very thick patient."

On a film made in this way, two measurements are taken. One is the "length" of the liver measuring from the highest point to the lowest border of the tip of the right lobe. The other is the "thickness," measured from the upper to the lower border in an oblique direction—"In a direction that would be considered the thickness if one were to lay the lower border on a horizontal plane."

Pfahler found that neither the sex, age, height, nor weight had much influence on the size of the liver. He gives the average normal length of the liver shadow as 21.3 centimeters, with normal variations from 18 to 22 centimeters, the longest being found in those that were the tallest and of the greatest weight. The average thickness is given as 12.8 centimeters, with normal limits of approximately 10 to 14 centimeters, the greatest thickness being found in those persons of the greatest body weight and hence the greatest body thickness. He says that when these limits are exceeded an explanation should be found.

THE ESOPHAGUS.

Compared to organic diseases of other portions of the alimentary canal, those of the esophagus must be considered as uncommon. Those occasionally seen are carcinoma, cardiospasm, diverticula, cicatricial stricture, ulceration, and varicose esophageal veins. Roentgenological examination is most important in the detection of any of these conditions.

Routine fluoroscopic observation of the act of swallowing should be a part of the examination of each patient to whom a barium meal is given. Not only will it detect those rare cases of diverticula, but displacements of the esophagus caused by mediastinal or thor-

acic lesions may be a valuable diagnostic finding. In making this examination the patient should stand behind the vertical fluoroscope in the right anterior oblique position with the chin turned over the left shoulder and the cup containing the barium mixture in the left hand. Current is sent through the tube and the patient slowly rotated back and forth until the clear space between the spine behind and the heart and aorta in front is at its widest. When this has been found, the patient is instructed to drink a swallow and the barium mixture is observed as it passes from the mouth, through the pharynx, and through this clear space into the stomach.

The usual liquid barium meal will pass rapidly down the esophagus. If the routine inspection of the esophagus leads to the suspicion of organic trouble, or if there be difficulty with swallowing or other symptoms that indicate esophageal involvement, a special examination should be made. For this a much thicker preparation than the usual meal should be used. Hirsch recommends a bismuth-acacia mixture, 1 part of mucilage of acacia to 4 parts of bismuth; barium may be substituted for the bismuth. This makes a thick, sticky mass which is fed to the patient a teaspoonful at a time. It passes slowly down the esophagus, clinging to its walls and so revealing whatever organic defects may be present. If there be symptoms of an obstruction which is not found with a liquid meal, observation of the swallowing of a 00-sized gelatin capsule filled with barium may show the probable location and cause of the lesion.

Roentgenograms of the esophagus should be made in the right anterior oblique position with the patient erect or prone. The amount of rotation of the patient should be the same as that at which the esophagus was best seen with the fluoroscope. If the patient be cautioned to remain immobile after the fluoroscopy has been completed, the room lights may be turned on and the position of the patient carefully noted. It then is easy to duplicate this position with the patient before the vertical cassette-holding device, the film occupying the same relative position as the fluoroscopic screen. Better films usually can be secured with the patient in the right anterior oblique position on the table. Manges points out the value of this position. The patient's right arm is placed along the trunk, the chin is turned over the left shoulder, the left knee is flexed, the left elbow is flexed and supports the patient, and the vertebral column is straight (Fig. 181). The correct degree of turning may be determined by horizontal fluoroscopy. An assistant holds a cup of the barium mixture in which is a short wide drinking tube. The patient takes two or three large swallows and then is told to stop and remain immobile while the exposure is made. Antero-posterior films are satisfactory for the cervical part of the

esophagus or for that part which passes through and is located below the diaphragm.

Wright and Freeman have found that the respiratory phase has a definite effect on the passage of an opaque meal through the esophagus. Barium swallowed at the end of a full inspiration passes at a leisurely rate through the esophagus; that swallowed during the middle of a respiratory expansion will pass rapidly into the stomach, while that taken at the end of a forced expiration will be delayed in the lower part of the esophagus for several seconds. This delay causes a dilatation of the lower part of the esophagus much like that seen in cardiospasm. In the examination of the

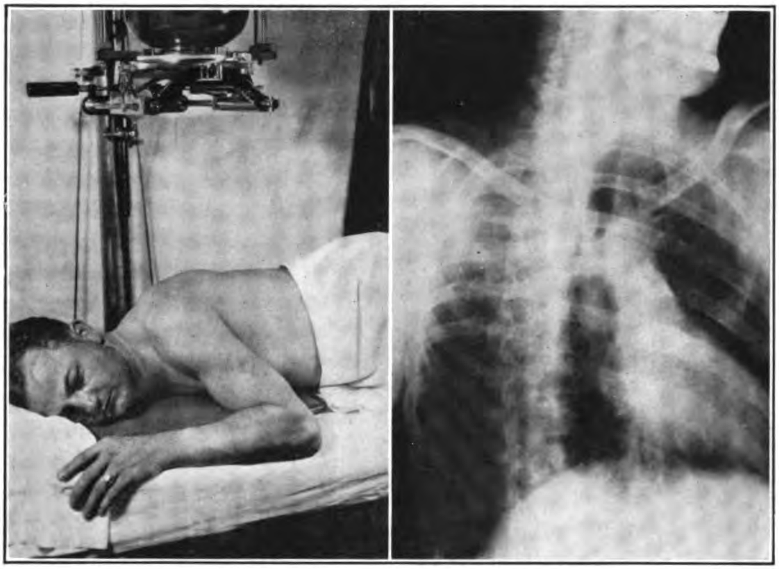

FIG. 181.—Right anterior oblique prone exposure of the esophagus. The esophagus is located in the space between the mediastinum and the vertebral column.

esophagus these observers recommend that the patient hold the breath at the end of full expiration while taking two or three large swallows of a thick barium mixture. This is retained in the esophagus long enough to make a thorough examination and to expose films even in the erect posture.

In centering the tube for roentgenograms of the esophagus it must be remembered that its average length is only 9 inches, that it begins above at the cricoid cartilage anterior to the sixth cervical vertebra, and that it terminates on the left of the tenth thoracic vertebra which is just below and on the left of the sternoxiphoid junction. Its midpoint would be about level with the angle of the sternum in front and the cartilage between the fourth and fifth

thoracic vertebræ behind. For antero-posterior views of the upper and lower ends the tube should be centered just above the jugular notch and over the sternoxiphoid junction. For the right anterior oblique view of the entire esophagus the tube should be centered at about the interval between the fourth and fifth thoracic vertebræ. For views of the entire esophagus the 11- by 14-inch film is adequate; for views of either the superior or inferior extent smaller films may be used.

THE STOMACH AND DUODENUM.

Roentgenologic examinations of the stomach and duodenum are of the greatest importance in detecting the presence of organic lesions and for determining changes in the size, shape, position, peristaltic activity, tonus, motility, and mobility of these viscera. Since they are not opaque to Roentgen-rays, the examination must be made by the use of some sort of meal that is opaque, thus creating an artificial density of their contents. Barium sulphate is the opaque substance now universally used. Formerly it was thought necessary to mix the powdered barium sulphate with some substance viscid enough to hold it in suspension. The material most commonly used was buttermilk or fermented milk. Malted milk, preparations of corn or potato starch, cooked cereals, and mixtures of gum acacia, gum tragacanth, or agar agar and water were also used. Colloidal aluminum hydroxide has recently been used for this purpose. Four ounces (120 grams) of barium sulphate in 12 to 16 ounces (360 to 480 cubic centimeters) of the suspending medium was the quantity used.

More recently the idea of a viscid suspending medium has largely been abandoned, and a satisfactory mixture is made with barium sulphate and water. In no instance is a volume greater than 8 ounces suggested. This smaller amount is adequate for an examination of the stomach. It has been found that if enough barium sulphate is used it will stay in suspension in water long enough for the examination, and that any food material in the mixture interferes with gastric emptying and with the regular passage of the barium through the small intestine. Equal parts of barium and water, 8 ounces of barium by weight to 5 ounces of water making a 7-ounce mixture; 5 ounces of barium sulphate and 3 ounces of water, and a 7-ounce volume of barium and water containing colloidal aluminum hydroxide are examples of barium meals that have been recommended more recently. Mixtures of ingredients to be made into meals by the addition of water are available commercially. Whatever preparation is selected, it should be stirred thoroughly, preferably with a mechanical mixer, just before it is used.

Soluble barium salts are poisonous. Barium sulphate used for *x*-ray diagnosis is prepared specially for that purpose with all the impurities and all the soluble salts removed. It should be purchased from reliable dealers in the original packages in which it comes from the manufacturers. Cases have been reported of deaths from the accidental administration of soluble barium salts instead of the insoluble sulphate. On two occasions in our experience the poisonous sulphite has been sent by druggists when the insoluble sulphate was ordered. If the patient is to take it at home, as in the double-meal method of examination, it is better to dispense the barium from the laboratory and not allow the patient to get it at a drug store on a prescription.

The first part of the examination of the stomach should be fluoroscopic with a small amount of barium mixture to study the mucosa of the stomach. When empty the mucosa is arranged in longitudinal folds called rugæ that have a definite arrangement within the stomach. This arrangement should be familiar to the examiner. Organic disease within the stomach interferes with this normal arrangement. By manipulation of the barium within the stomach, this pattern is examined carefully, and enough of it may be displaced through the pylorus to examine the duodenal cap also. In order better to examine certain parts of the stomach, it may be necessary to place the patient in the horizontal position on a fluoroscopic table and turn him from side to side to permit the barium to gravitate into the dependent parts of the stomach.

The fluoroscopy of the mucosa of the stomach may reveal findings that should be studied on films exposed especially to show the mucosal folds. Many methods have been suggested for such an examination. Possibly the simplest is to give the patient a small amount of barium in water. Too large an amount will efface the mucosal folds and defeat the purpose of the examination. This barium may be spread over the interior of the stomach by manual manipulation, or it may be spread out by rotating the patient from the left lateral to the supine, to the right lateral, to the prone position on the *x*-ray table. The films may be exposed in the supine position for folds in the upper part of the stomach and in the prone position for those in the body and antral portions.

When the study of the mucosa has been completed, the remainder of the opaque material may be ingested and the stomach filled.

Many different methods and procedures have been advocated for the roentgenologic examination of the stomach and duodenum. Before the perfection of the transformer-type of apparatus, dependence had to be placed on fluoroscopic study. Exposures required such a length of time that all the images on the plates were blurred

by peristaltic motion. After it became possible to make exposures short enough to obtain satisfactory images, more dependence was placed on plates and films. At this time the serial method of examination was originated by Cole. This consists of the exposure of at least eight films or plates of the stomach in each of three postures, the erect, the prone, and the right oblique prone. This serial method requires an expenditure of materials not possible in many places. Perhaps the most generally adopted method of study of the stomach and duodenum is a combination of fluoroscopy with the exposure of a greater or less number of films for more detailed study and for purposes of record.

Considerable practice and experience are required to learn fluoroscopy of the stomach and duodenum. Barclay emphasizes the importance of adopting a routine method of making such examinations. The erect posture with a vertical fluoroscope is best. With the patient in this position and the examiner seated on a chair or stool, the first examination is made with a small amount of opaque mixture. This may be thick or thin as the examiner wishes. Carman used barium sulphate and water; Barclay uses a thick emulsion. The thin suspension of the barium may be moved about within the stomach by the examiner and displaced from part to part until the entire stomach has been examined. The thick emulsion or paste can be observed as it canalizes the empty stomach; then it can be spread out over the interior of the stomach. When all the meal has been taken, the entire stomach and the duodenum should be examined carefully for abnormalities in size, shape, position, correspondence with the patient's habitus, tonus, peristalsis, mobility, and especially for filling defects. Filling defects of ulcer in the stomach most often are located on the lesser curvature, but both surfaces of the stomach should be inspected carefully. In many instances in the direct postero-anterior projection on the screen, some part of the stomach or duodenum is obscured by other portions, making it necessary to turn the patient so that all parts may be seen. Most commonly the duodenal cap is located behind the prepyloric portion of the stomach, requiring rotation of the patient to the right anterior oblique position for an unobstructed view of it. Fluoroscopy in various horizontal positions often gives valuable information. This is especially true in the supine and Trendelenburg positions which permit the opaque meal to gravitate into the fundus of the stomach and into hernias of the esophageal hiatus.

The number of films of the stomach and duodenum that should be taken depends on the symptoms presented by the patient and the results of the preliminary fluoroscopy. If these be clear-cut, either negative or positive for disease, often a film or two for pur-

poses of a permanent record are all that are necessary. If there be suggestive symptoms or suspicious fluoroscopic findings, it may be necessary to expose a number of films of the stomach and duodenum or of some particular portion in which a disease process is suspected. This is especially important for small lesions along the lesser curvature, for lesions involving the pylorus, and for ulcerative disease of the duodenum.

Films of the stomach for lesions in the stomach may be made in the erect position, in the prone position, in the right lateral position, in the right anterior oblique position, and in the supine position. The choice of position for a particular patient depends on the part that is to be specially examined and on the location and shape of the stomach and duodenum, these depending largely on the body habitus of the individual.

In the change from the erect to the prone position there is considerable change in the form and position of the stomach. Moody, Chamberlain, and Van Nuys, who have studied this subject in healthy adults from the anatomical standpoint, say that: "These changes are due to several factors, chief of which are: (1) a movement cephalad of the whole stomach; (2) a movement of a large part of the contents of the stomach into its cardiac end; (3) a decrease in the long axis of the stomach with an increase in its transverse axis; (4) a movement cephalad and to the right of the pyloric end of the stomach. This movement is sometimes so modified that the pylorus moves to the left instead of to the right. There are many combinations of these movements." With the patient prone these investigators found that there was but little difference in the position of the most caudad part of the stomach in males and females; in all but approximately 13 per cent the entire stomach was above the interiliac line, and none was more than 2 inches below this line. They also found that the midpoint of the pylorus varied in position from approximately 8 centimeters on the right of the median plane to 2 centimeters on the left, the most common location being in the zone between 2.5 and 5 centimeters (1 and 2 inches) on the right (Fig. 183).

By exposing films of a number of individuals in the postero-anterior erect, the postero-anterior prone, the right anterior oblique, and the right lateral positions and correlating the findings on them with the patients' body habitus, Miss Vick was able to arrive at general conclusions about the preferred position for roentgenograms of the stomach. For asthenic individuals (see Fig. 177) films may be exposed in the postero-anterior erect or prone positions. In the erect position the film must reach as low as the pubis; in the prone position the lower border should be 2 inches below the highest

levels of the iliac crests; 4 inches to the right of the spine for the right margin will include all of the duodenum.

In hyposthenic individuals the postero-anterior prone position is preferred. The film is placed with the inferior border level with the iliac crests and the right margin 3 inches to the right of the spine (Fig. 182). For patients of the sthenic habitus the right anterior oblique horizontal position is necessary. In the prone position the duodenal cap will be overshadowed by the pyloric end of the stomach. The film is placed with the inferior margin above the iliac crests and the right margin including all of the shadow of the spine.

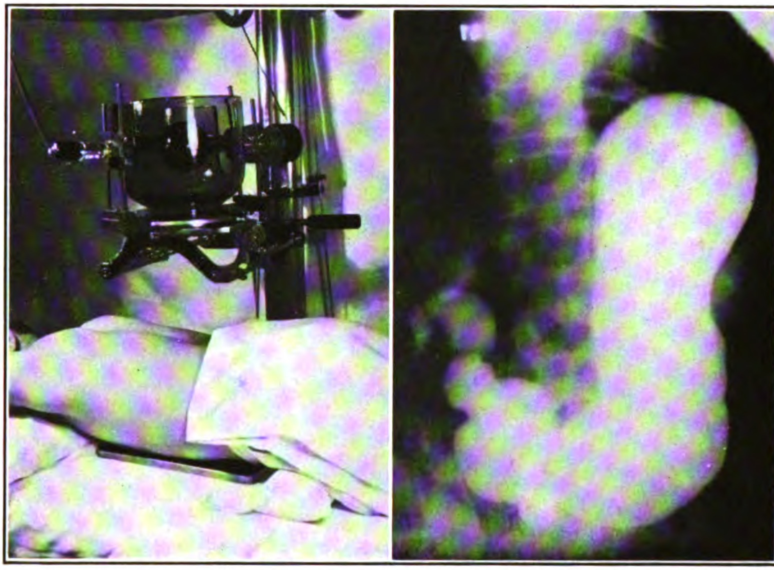

Fig. 182.—Postero-anterior prone exposure of the stomach. The hips are elevated on a sand bag and the upper part of the thorax on a pillow.

Most difficulty was experienced with those patients of the hypersthenic habitus with high, hypertonic, steerhorn-shaped stomachs. The right anterior oblique and the right lateral positions were required for these patients. Often to show the duodenal cap at all it was necessary for the films to be taken in the right lateral position. The size and thickness of these patients makes these exposures very difficult. The lower margin of the film need not be lower than the lower limit of the ribs, and all the pylorus and duodenum will be located anterior to the vertebræ.

Positioning of patients for films of the stomach may be based on fluoroscopic examinations. If the films be taken in relatively the same position that showed the stomach and duodenum to best

advantage during fluoroscopy, the position usually will be correct. If the equipment includes a horizontal fluoroscope, the posing in the prone, right anterior oblique, or other position usually is simple. This is the preferred procedure. If a horizontal fluoroscope is not available, then the positioning must be based on the habitus and it may be necessary to make and develop trial exposures, changing the position until the best position has been secured. An opaque marker in the form of a metal disk fastened to the patient's umbilicus may assist in localization.

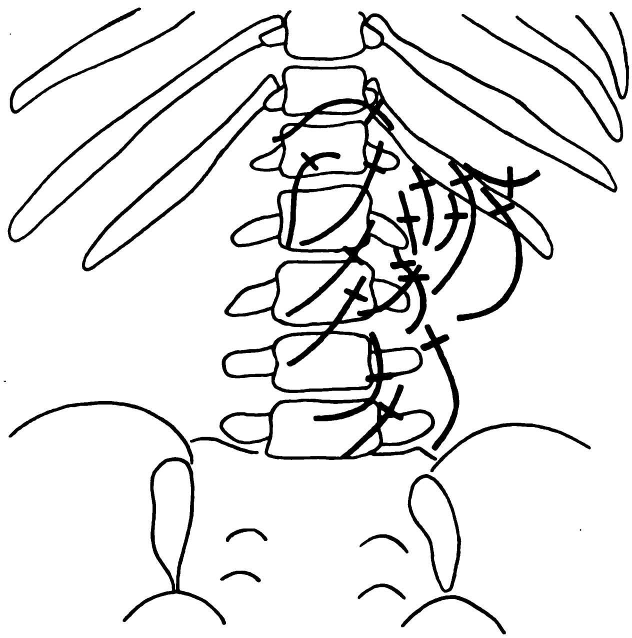

FIG. 183.—Showing variations in the position of the pylorus and duodenal bulb on films of the stomach made in the prone position. The longer lines represent the middle of the duodenal bulb and pyloric antrum; the cross lines represent the pyloric sphincter.

Serial roentgenograms of parts of the stomach and duodenum are made to show those permanent defects upon which are based the diagnosis of organic lesions. Since the stomach constantly is changing its shape and the duodenum fills and empties, on almost any single film there are irregularities in contour that may be suggestive of organic lesions. It is only when these are in the same position and of the same shape and size in a series of films or constantly present during a fluoroscopic examination that a diagnosis of a permanent defect with pathological significance can be made. Such a series may be made by exposing a number of films with or

without a device for changing them, such as a Cole plate-changing table. By means of some simple device multiple small exposures may be made on one large film.

Perhaps the simplest as well as one of the best of these is a Pirie tunnel that permits of making four exposures on one film which may be of the 10- by 12-, 11- by 14-, or 14- by 17-inch size. This consists of a tunnel large enough to accommodate the cassette and a tray or pan by means of which the cassette may be moved in the

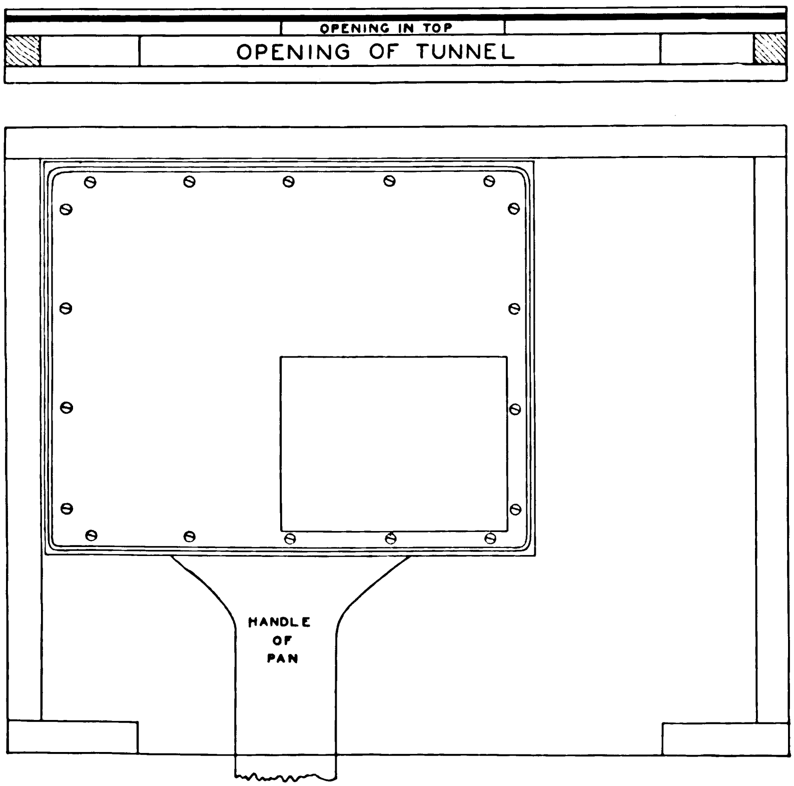

FIG. 184.—A cassette-shifting tunnel for multiple exposures of the stomach, using a 11- by 14-inch cassette.

tunnel (Fig. 184). In the top of the tunnel there is an opening which is one-fourth the size of the film, the tunnel being of such dimensions that when the cassette is pushed into one corner the opposite fourth of the film is under the opening in the center, the rest being covered by sheet lead in the top of the tunnel. This apparatus is placed on the x-ray table and the patient arranged on it. The position of the patient with reference to the opening in the tunnel may be controlled by horizontal fluoroscopy; if the equipment does not include a

horizontal fluoroscope, the proper position of the patient may be determined by making a trial exposure with an opaque disk on the patient's umbilicus, the position then being adjusted by placing the umbilicus over the appropriate part of the opening in the tunnel (Fig. 185). Serial exposures of the stomach and duodenum are intended to produce roentgenographic evidence in quantity, the number of exposures depending on the type of examination being made. With a Pirie tunnel eight exposures in one position usually are sufficient, but more than one projection may be necessary.

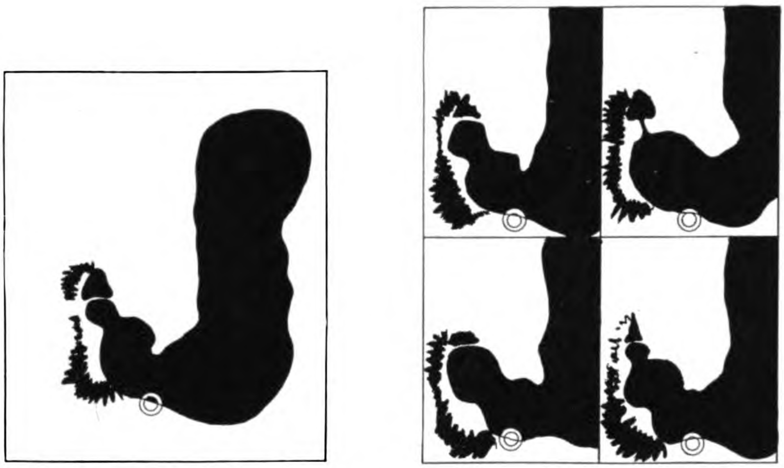

Fig. 185.—Multiple exposures of the stomach on a single film, using the device shown in Fig. 184. If a horizontal fluoroscope be not available, a metal washer may be fastened over the umbilicus, a large film exposed and developed, and the patient arranged over the opening in the cassette-shifting device with the umbilicus placed so that the desired portion of the stomach will be shown.

Emphasis recently has been placed on the exposure of small film areas of certain selected portions of the stomach and duodenum while pressure is being exerted to reduce the barium content to a thin layer. This requires special apparatus. Such apparatus is often called a spot-film device. Essentially this is a device attached to a fluoroscopic screen by means of which an area can be selected fluoroscopically, a variable amount of pressure exerted, an x-ray film moved over this area, and an exposure made, all in rapid succession. With some of the more elaborate spot-film devices, as many as four such exposures may be made on a single film. By means of a special change-over switch, shifting the cassette to the exposure position automatically changes the machine settings from those for fluoroscopy to those for the film exposures.

THE SMALL INTESTINE.

Until recently little attention was paid to the examination of the small intestine during a routine study of the gastrointestinal tract. At present, at least the proximal portion of the jejunum and the distal portion of the ileum are included as a part of every gastrointestinal study, and special small-intestinal examinations are made whenever there are indications for them.

For this purpose mixtures of barium sulphate and water are used. Morse and Cole said that a meal to be used in examining the small intestine must be of such composition and consistency that it will pass out of the stomach at a fairly uniform and rapid rate, and it must be of sufficient consistency to pass through the intestine evenly and preferably fairly slowly. Eight ounces by weight of barium sulphate and 5 ounces of water, making a moderately thick paste of about a 7-ounce volume, is recommended. Other examiners use other proportions: 5 ounces of barium sulphate and 3 ounces of water, equal parts of barium and water, etc. Food substances of all kinds should be omitted from the mixtures, for all of them cause irregularity in the emptying of the stomach and passage of the barium through the small bowel.

The examination should be both fluoroscopic and roentgenographic. Since a barium-water meal will reach the cecum in from one and a half to three hours, and will empty from the small intestine in from five to seven hours, it is difficult to set definite intervals for the observations. Probably the best procedure is to make the first examination a relatively short time (fifteen to thirty minutes) after the meal has been ingested. The patient should be examined supine on a fluoroscopic table and a 14- by 17-inch film exposed in the prone position. From this the proper time for the next examination may be determined. The patient should be seen often enough to permit a thorough investigation of the entire small bowel while the barium is passing through it. If dependence is placed entirely on films, these should be exposed at half-hour intervals until the barium has entered the large intestine.

Gershon-Cohen and Shay describe a method of examining the small intestine by filling through a duodenal tube passed into the second or third portion of the duodenum. Eight hundred to 1200 cubic centimeters of a barium-water mixture (in proportions of 3 ounces barium to 250 cubic centimeters of water) are used. Gravity flow at a height up to 10 inches, or injection with a syringe, or a special apparatus described by the authors that permits of the injection in quantities of 5 cubic centimeters are methods of intro-

ducing the barium mixture. The filling is done under fluoroscopic control. By separating the coils under the fluoroscopic screen, and by stopping after each 200 cubic centimeters for the exposure of a film, a satisfactory examination of the small intestine can be made. After the barium has been injected, air may be introduced in quantities of 5 cubic centimeters for a double-contrast examination of the small bowel.

Suspected obstruction is one of the conditions that always calls for a roentgen examination of the small intestine. Distended coils of the small intestine on films exposed with the patient prone, distention associated with air-fluid levels in the small bowel on films exposed with the patient erect or postero-anteriorly with the patient horizontal and in the lateral position, are findings of great diagnostic importance. A small amount of barium mixture by mouth may help visualize the distended coils and may give additional information as to the location and cause of the obstruction. Large meals probably should not be ingested.

Intestinal intubation is of great aid in the diagnosis and treatment of obstruction in the small bowel. This is usually done with a long rubber tube; the one known as the Miller-Abbott tube is most often used. This has two openings through it, one reaching to the end of the tube, the other reaching a small rubber balloon near the end. The tube is introduced into the stomach and into the duodenum in the usual way. This can be done advantageously under fluoroscopic control. When the tube has entered the second or third part of the duodenum, the balloon is inflated. Gentle suction is applied to remove the accumulated fluids and gas. Peristaltic activity of the intestine will advance the tube and the balloon to the point of obstruction. Its progress must be studied at short intervals by roentgen examinations. When forward progress of the balloon has stopped, an examination after the injection of a small amount of barium through the tube will assist in locating the obstruction and determining its cause.

THE ILEOCECAL REGION AND APPENDIX.

The terminal portion of the ileum, the cecum, and the appendix are included in all complete examinations of the gastrointestinal tract. Particular attention is paid to this region at the sixth-hour examination, and sometimes a special examination is made at a nine-hour interval after ingestion of the barium meal. The cecum and appendix are examined at the twenty-fourth hour examination and during the barium-enema examination of the colon. In many instances it is possible to fill the terminal ileum with the barium

enema. If this can be done, it is better filled and visualized than when filled by the meal.

There is considerable variation in the location of the terminal ileum, the cecum, and the appendix. Normally the coils of the distal part of the ileum are located in the small pelvis, the terminal portion rising along the medial side of the cecum to terminate in the ileocecal junction. These structures have a considerable range of mobility. In the erect position the cecum will be found in the small pelvis in more than half the persons examined. In the change from the erect to the supine or prone position, all these structures, unless adherent, move upward for a variable distance. In examinations in these positions, the cecum is usually out of the pelvis in the right iliac fossa.

The cecum, the terminal ileum, and the appendix may be located in the right side of the abdomen even as high as the under surface of the right lobe of the liver or in front of the right kidney. The cecum may fail to descend and be directed upward in the subhepatic region. On the contrary, the cecum may be located in the middle or even in the left side of the small pelvis. The position of the appendix is variable. From its attachment to the cecum, most often it extends to the left with an upward or downward inclination. It may be looped below the cecum, it may extend along the medial or lateral aspect of the cecum, or it may be retrocecal in location.

At the sixth-hour examination the normal position of the barium meal is in the terminal part of the small intestine, in the cecum, and in the ascending colon usually as far as the hepatic flexure. The exact position of the meal depends on a number of factors. The kind of opaque mixture, the rapidity of emptying of the stomach, the general tonus of the small intestine, the presence of inflammatory adhesions around the cecum and ileum, and the state of tone of the musculature of the colon are conditions that will influence its position. At nine hours the small intestine normally should be empty. According to Kantor a residue at this time indicates ileal stasis.

Much of the information about the structures in the right lower quadrant of the abdomen is obtained by fluoroscopy. This should be done in both the erect and supine positions. By fluoroscopic manipulation, fixation of the appendix, cecum, or terminal ileum can be determined; by fluoroscopy it is possible to determine whether or not tender points are located over the appendix and cecum, and it can be determined whether such tenderness does or does not shift in position with the change in position of these structures. From roentgenograms may be told the position, size, shape, etc., of the appendix, deformities of the cecum, and kinks and filling defects in the terminal ileum.

Roentgenography of the ileocecal region is relatively simple. Unless it be necessary to alter the position of the patient to show a retrocecal or displaced appendix, all films are made in the prone position. The highest point of the greater trochanter of the femur is the landmark for placing films for exposures of this region (Fig. 186). It is nearly on the same level with the most inferior part of the small pelvis and also is in the lateral margin of the body, so that

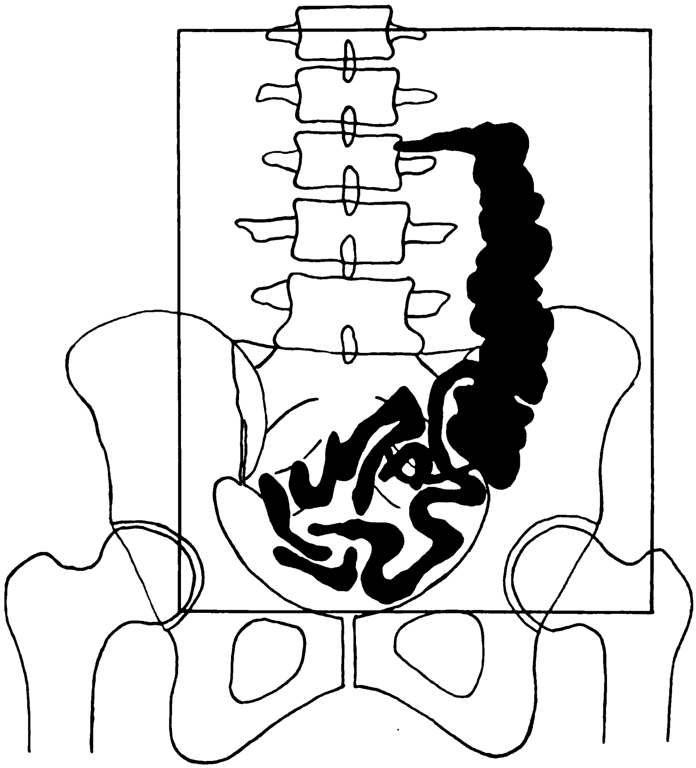

FIG. 186.—Postero-anterior view of the ileocecal region on a 10- by 12-inch film, patient prone, with the right inferior corner of the cassette level with the greater trochanter of the right femur.

if the inferior lateral corner of the cassette be level with this point, the film will be in the proper position. The tube should be centered with the central rays entering just below the highest point of the iliac crest. A film that is 10 by 12 inches in size will include all important structures.

THE LARGE INTESTINE.

Twenty-four hours after the ingestion of an opaque meal all the barium should be in the large intestine. Usually it is found scattered from the cecum distally into the descending colon. The pelvic

portion of the colon and the rectum will be poorly defined. The location of the barium is somewhat variable, depending chiefly on the degree of tone of the musculature of the colon. If a hypertonus or spasticity be present, the barium usually will be widely scattered in rather small masses; if the tonus be decreased, often it will be accumulated in a dilated cecum and ascending colon, the distal part reaching as far as the middle of the transverse portion.

At the twenty-fourth-hour examination the patient is examined for the position, size, and shape of the large intestine; the rate of progress of the barium mass and the tonus of the gut are determined; the cecum and appendiceal region are carefully palpated, and the filled portion is examined carefully for evidences of organic lesions, such as diverticula, chronic ulceration, and carcinoma. With a normal emptying of the stomach barium in the ileum at this time is an important indication of obstruction, usually from inflammatory adhesions in the ileocecal region.

Examinations of a meal in the colon more than twenty-four hours after its ingestion often are made to determine the cause of delay in emptying. By the end of forty-eight hours the large intestine normally should be nearly empty of an ingested meal. Such examinations usually are made with the fluoroscope, films being made for purposes of record.

To complete a gastrointestinal examination, a barium enema is necessary. As a routine this may be given immediately after the twenty-fourth hour examination of the meal in the colon. There will be some differences in the density of the ingested barium and that in the enema which detract from the results, but it is possible to locate gross lesions in this way. If there be indications of disease, it is a better procedure to empty the large intestine of retained barium, fecal material, and gas before the barium enema is given. This may be done by giving a laxative the night before the examination, followed by a cleansing enema the next morning. Compound licorice powder in a dose of 1 to 2 teaspoonsful seems to be the laxative preferred by most roentgenologists. Castor oil or one of the saline laxatives may be used. The enema may be of plain water, soapsuds, normal saline solution, or water containing 1 teaspoonful of baking soda to the quart. An ampoule of pitressin after the enema insures complete evacuation (see p. 217).

The opaque enema should be fluid enough to pass readily through the enema tip, it should not be irritating, it should contain enough barium to render the colonic contents opaque, and it should be large enough to fill the entire colon. Eight ounces (250 grams) of barium sulphate in a mixture of 2 quarts (2 liters) of water with enough powdered gum acacia to hold the barium in suspension make a good

enema. The mixing should be thorough; it is best done with an electric mixer. At the present there are commercial preparations in the form of powders that make satisfactory enemas, are easy to prepare, and may be kept until required.

An enameled-ware enema can fitted with 5 to 6 feet of rubber tubing, a cut-off clip, and a large size enema tip or small colon tube is satisfactory for injecting the enema. The tip need not reach farther into the rectum than well past the sphincters. A rubber syringe bulb in the tubing often is of considerable assistance in starting the enema or dislodging lumps that occasionally may occlude the tip.

If the equipment includes a horizontal fluoroscope, it should be used in giving opaque enemas. The patient is placed in the supine position, the tip inserted, and the can held at a height of not more than 2 or 3 feet above the table. The clip is released, and the filling of the colon by the enema is observed with the fluoroscope.

Some little time is required for the rectal ampulla to fill. There will be a delay in the passage of the enema out of the small pelvis, following which the colon as far as the splenic flexure will fill rapidly. At the splenic flexure, at the place the colon passes anteriorly across the vertebral column, and again at the hepatic flexure, there will be other periods of delay. By the time the enema has reached the cecum, all parts distal to it will be well filled. During the injection of the enema, palpatory manipulations with the patient in different positions enable one to make a careful search of the entire colon for evidences of disease. Usually the enema will pass through the ileocecal junction into the terminal ileum and it can be examined. The best filling of the ileum is obtained in this way.

For purposes of record at least one film of the colon should be made. Since the loop of colon that crosses the inlet of the pelvis on the left side will be incompletely filled in the supine position, the patient should be turned to the prone position for this film. For picturing the entire colon a 14- by 17-inch film is required. The lower border should be located about 2 inches below the superior parts of the greater trochanters of the femora or about the same distance below the tip of the coccyx (Fig. 187). The central rays should be directed into the vertebral column just above the superior parts of the hip bones. In addition to the large film smaller films of parts of the colon with the patient in the supine or prone position may be made; or, to show defects obscured in direct exposures, one or more oblique views may be necessary.

When the examination of the filled colon has been completed, the patient is permitted to discharge as much of the enema as

possible. A fluoroscopic examination then is made, and, if indicated, films are exposed. At these examinations the mucosal pattern is best shown.

Some lesions of the colon are more or less obscured by a barium enema. These include polyps, ulceration, and other small lesions of the mucosa. For these a double-contrast enema is valuable. Starting with a completely empty colon, the patient is first given a barium enema of the consistency of cream. Care is taken not to

FIG. 187.—Postero-anterior views of the colon filled with a barium enema, showing some of the normal variations in size, shape, and position. For such exposures the inferior edge of a 14- by 17-inch cassette should be about 2 inches below the highest parts of the greater trochanters of the femora.

fill the colon so completely that the barium will pass into the terminal ileum. The patient is instructed to discharge this enema as quickly as possible to prevent the barium from settling to dependent portions of the colon. After this has been done, the patient is returned to the fluoroscopic table and the large intestine is inflated with air by means of a large catheter or a colon tube and a rubber bulb. The distended colon is examined fluoroscopically, and stereoscopic films are exposed with the patient in the prone position, using a Potter-Bucky diaphragm.

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CHAPTER XX.

THE URINARY TRACT.

THE urinary tract includes the kidneys, the ureters, the urinary bladder, and the urethra. The shape of the kidneys is too well known to need description. Each kidney is about 4 inches in length, $2\frac{1}{2}$ inches in width, and $1\frac{1}{2}$ inches thick. The left usually is slightly longer and more slender than the right. They are located in the upper posterior part of the abdominal cavity. The upper pole of each kidney usually is at the level of the body of the twelfth thoracic vertebra, and the lower at the level of the body of the third lumbar vertebra (Fig. 188). The left is slightly higher than the right, its upper pole reaching the eleventh rib while that of the right reaches as high as the twelfth rib or eleventh intercostal space. The long axes of the kidneys are not directed vertically but they incline laterally and inferiorly nearly parallel with the edges of the psoas muscles.

There is some variation in the position of the kidneys depending on body architecture. As a rule they are somewhat higher in those of the hypersthenic than in those persons who are of asthenic habitus. This is not so marked as the variation in position of different parts of the gastrointestinal tract. The respiratory excursion of the kidneys is from $\frac{1}{2}$ to $1\frac{1}{2}$ inches. There also is a slight displacement downward in the change from the supine to the erect position. Movements of these kinds are slightly more pronounced on the right than on the left side.

In a majority of instances the kidney pelvis is located at the level of the space between the transverse processes of the first and second lumbar vertebræ. The junction of the kidney pelvis and the ureter most often is at the level of the transverse process of the second lumbar vertebra (Fig. 188). From this point each ureter extends downward with a slight inclination medially, crossing the transverse processes of the third, fourth, and fifth lumbar vertebræ, crossing each process slightly nearer the midline than it does the one just above. As seen in roentgenograms the normal ureter may be straight or slightly wavy in its abdominal course. It enters the pelvis anterior to the sacroiliac joint and passes downward, forward, and slightly farther medially to enter the bladder at about the horizontal level of the spine of the ischium (Fig. 188).

The position of the urinary bladder depends largely on its degree of distention. As a rule in adult males the level of the trigone, the

most fixed and inferior portion, is that of the middle of the symphysis pubis, and in adult females that of the inferior limit of the symphysis. Distention raises the superior surface above the symphysis for a variable distance. In infants and young children the bladder is located higher, being all above the pubes, and in location therefore an abdominal organ.

The density of the kidneys is slightly greater than that of the surrounding structures. Their density is sufficient that their out-

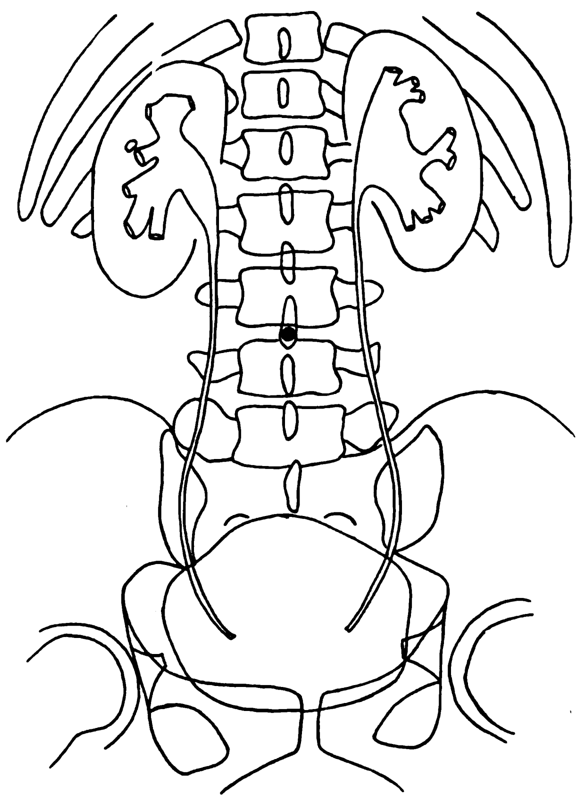

FIG. 188.—Drawing showing different parts of the urinary tract.

lines can be shown on roentgenograms through nearly their entire extent. This makes it possible by means of roentgenography to determine their size, shape, and position, their relative density, and the presence of calcareous and other deposits in the form of calculi. With the assistance of the urologist in the performance of pyelography, much other important information with reference to renal disease may be obtained.

Roentgenography of the ureters usually is undertaken to deter-

mine the presence of ureteral stones. By the injection of an opaque solution, dilatations and abnormalities in diameter, outline, and course can be detected. Roentgenograms of the bladder are made for calculi and, after injection with an opaque solution or air, for the presence of tumors, diverticula, etc.

Whenever the condition of the patient permits, preliminary to examinations of the urinary tract steps should be taken to rid the intestinal tract of fecal material and gas. If the patient is ambulatory, usually a simple enema will suffice. Pitressin probably should not be used before intravenous or excretory urography (see p. 430). If the patient has had an attack suspected of being renal colic and morphine has been given for relief, the large intestine usually is distended with gas that is very difficult to dislodge. If the condition of the patient is such that it would be difficult for an enema to be discharged completely, perhaps the examination should be conducted without preparation, for a transverse colon filled with an enema is more objectionable than one in which there is some gas and fecal material. The preparation of patients has been discussed on p. 217.

Routine examinations should include the entire urinary tract. Calculi often are found in both kidneys or in the kidney and ureter of the same or the opposite side. For persons of small or medium size the entire urinary tract can be included on one film; for persons of large size two films are necessary, one for the kidneys and upper portions of the ureters and the other for the bladder and lower portions of the ureters. Stereoscopic films, films in two positions for the bladder, and occasionally a film in the transverse direction, are required for complete examinations.

For the best roentgenographic examination of the urinary tract a Potter-Bucky diaphragm is essential. The patient should be placed over the diaphragm in the supine position with the head well supported and the knees elevated. With the tube over the center of the diaphragm, for an exposure lengthwise of a 14- by 17-inch film the patient should be placed with the sternoxiphoid junction and the upper borders of the pubes the same distance from the top and bottom of the film. If this distance be 2 inches or more, the entire urinary tract will be included on the film. If two films are to be taken, one for the upper and the other for the lower part of the tract, the 11- by 14- or the 14- by 17-inch size may be used. If the upper margin of the film be 2 to 3 inches above the sternoxiphoid junction, all of the upper part of the tract will be included (Fig. 189); if the lower margin be the same distance below the upper borders of the pubes, all of the lower part will be shown (Fig. 190).

In urinary-tract roentgenography it is advisable to use compression. This assists in immobilizing the kidneys, prevents motion

from involuntary respiratory movements, and tends to force the air-filled portions of the colon into the lateral parts of the abdomen. Special inflatable rectangular compression bladders for this purpose are available commercially. A rubber basket-ball bladder may be

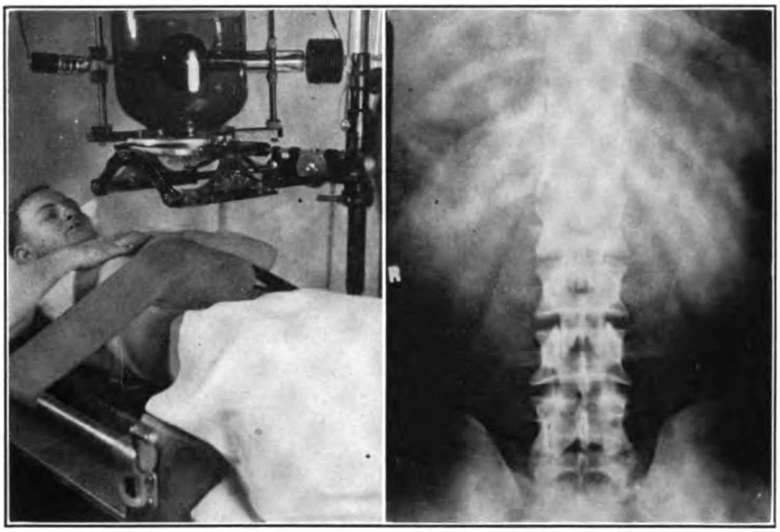

FIG. 189.—Antero-posterior exposure of the upper part of the urinary tract. The tube is centered over the midline 1 to 2 inches above the navel.

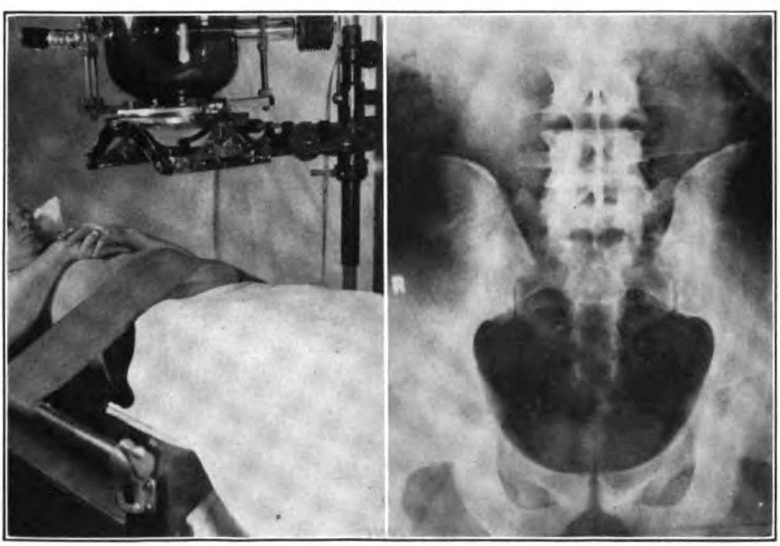

FIG. 190.—Antero-posterior exposure of the inferior portion of the urinary tract. The tube is centered over a point at the junction of the upper two-thirds with the lower third of a line extending from the umbilicus to the symphysis pubis.

used for the same purpose. Either should be partially inflated and placed under the compression band of the Potter-Bucky diaphragm.

Since the kidneys move from ½ to 1½ inches with each respiration, depending on its depth, respiration should be stopped during the exposures. Only under exceptional conditions should the exposure time exceed five seconds; with thin patients it may be as short as two and a half seconds.

In many laboratories stereoscopic films at least of the upper part of the urinary tract are made as a routine procedure. A tube shift along the midsagittal plane of the body is preferable. After the patient, film, and tube have been arranged as described above for a single film, if the tube be shifted half the distance toward the feet, the setting will be correct for the exposure of the first film. After it has been exposed, the patient is permitted to breathe quietly but should not move while the cassette is being changed and the tube shifted the full distance toward the head for the second film. The breath should be held, preferably in complete expiration, for both exposures.

When a special examination for stone in the urinary bladder is being made, it often is advisable to make an exposure through the pelvis with the patient in the prone position. For this the patient is placed with the symphysis below the center of the diaphragm. The cassette is placed with its lower margin below the highest parts of the greater trochanters. The tube should be tilted upward to throw the shadow of the bladder above the symphysis. A tilt of 15 degrees is sufficient. This is permissible with a Potter-Bucky diaphragm as long as there is no lateral displacement of the tube. The central rays should be centered over the middle of the supero-inferior extent of the gluteal fold (Fig. 191).

Without the aid of a Potter-Bucky diaphragm roentgenography of the urinary tract is more difficult. To obtain the best results, a number of exposures should be made using a small cone and relatively small films. One exposure should be made for each kidney and the upper part of each ureter, one for the middle portions of the ureters, and one for the lower parts of the ureters and the bladder, making four exposures in all (Fig. 192).

For the films of the kidneys the tube is centered with the central rays directed into a point halfway between the sternoxiphoid junction and the umbilicus and from 2 to 3 inches lateral to the midline of the body. An upward tilt of the tube of 5 degrees and compression of the cone of the tube stand against an inflated rubber bag are of considerable aid. For the film of the middle portions of the ureters the tube should be placed over the umbilicus with the rays directed perpendicularly to the table top and the film placed accordingly.

For the view of the bladder the tube should be centered over a point midway between the umbilicus and symphysis pubis and tilted toward the feet at an angle of 5 degrees. The cassette is placed with the lower margin of the film about 2 inches below the tops of the greater trochanters.

For small films of different parts of the urinary tract a small cone should be used. Since compression always is necessary, the cone should be large enough to cover just the region being examined at the distance resulting when the pressure of the cone against the rubber bag is applied. A cone with a diameter of 5 inches at the large end is satisfactory. The anode-film distance may be controlled to a limited extent by the degree of inflation of the compression bag.

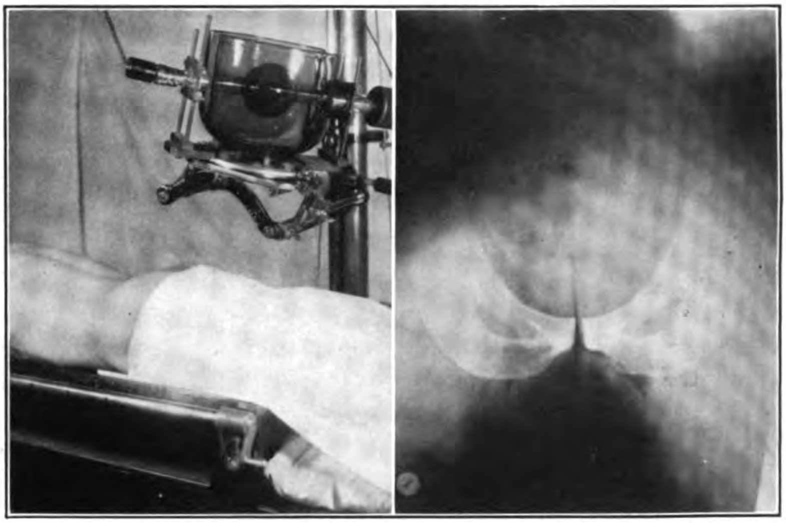

FIG. 191.—Postero-anterior oblique exposure of the urinary bladder. The patient is placed so that the shadow of the pubis will fall below the middle of the film, the tube is moved toward the inferior part of the Potter-Bucky diaphragm and tilted upward at an angle of 15 degrees. The central rays enter through the middle of the gluteal fold.

Urography is a term used by Braasch to designate the roentgenologic study of the different parts of the urinary tract made radiopaque by the injection of pyelographic and other contrast solutions. Under this heading are included pyelography (the pelves of the kidneys), ureterography (the ureters), cystography (the urinary bladder), and urethrography (the urethra).

Pyelography and ureterography may be done in two ways. In the first of these, now known as retrograde pyelography, an opaque solution is injected into the pelves of the kidneys and the ureters. This must be done by a physician skilled in the use of a cystoscope—

one able to introduce small catheters into the ureters. In the second, known as intravenous urography, a preparation is injected intravenously that is excreted by the kidneys, rendering the urine in the kidneys, ureters, and bladder opaque to Roentgen-rays. Retrograde is more satisfactory than intravenous pyelography, yet both have a place in diagnostic work.

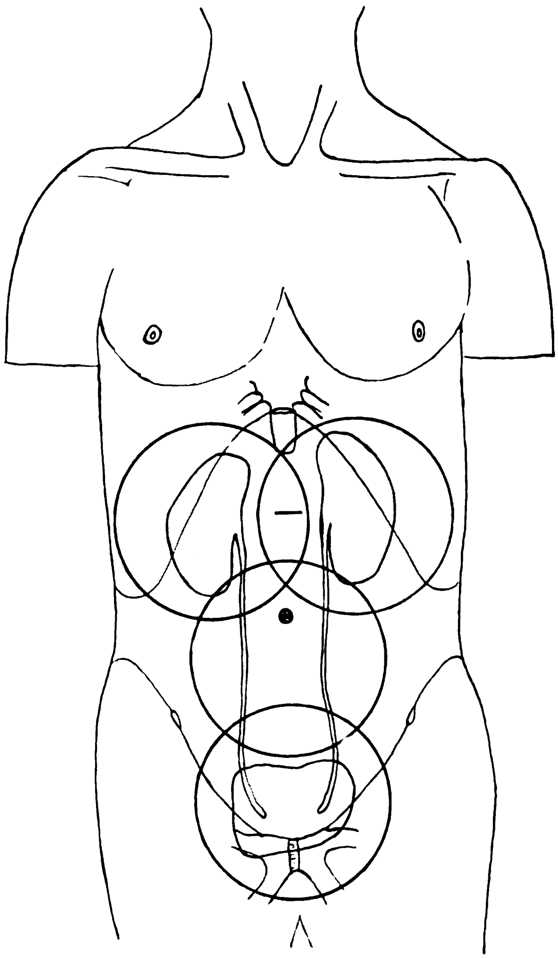

FIG. 192.—Showing the areas to be included on small films of the urinary tract exposed without a Potter-Bucky diaphragm.

There is very little difference in the roentgenographic technique in ordinary urinary-tract examinations and that used in urography. A special cystoscopic table equipped with a Potter-Bucky diaphragm is desirable for retrograde pyelography. Such work can be done

with a diaphragm on an examining table, but the diaphragm must be protected from the solutions used during the procedure. For pyelograms and ureterograms the technique given for examinations with a Potter-Bucky diaphragm will be satisfactory.

A double-shift exposure sometimes is made with radiopaque ureteral catheters in the ureters in an attempt to determine whether or not a particular shadow is cast by a ureteral stone. An exposure of this kind is made by shifting the tube transversely about the same distance that would be used for stereoscopic films and making two exposures on the same film. Each exposure should be about two-thirds the normal exposure. Respiration should be suspended during each exposure.

Intravenous or excretory urography depends on the intravenous injection of some preparation that is rapidly excreted by the kidneys into the urine. The high iodine content of these preparations renders the urine radiopaque and makes it possible in many instances to picture the renal pelves, ureters, and bladder. Intravenous urography can be done in any *x*-ray laboratory with the usual equipment. Some preparation of the patient is advisable. This should be directed toward freeing the intestinal tract as much as possible of fecal material and gas. In order that the urine be as concentrated as possible, thus giving the highest concentration of the iodine in the urine, the patient should refrain from eating and drinking for the preceding twelve to fourteen hours.

Severe reactions occasionally follow the injection of iodine preparations for excretory urography, and several deaths have been reported. The symptoms produced include flushing, nausea, urticaria, vomiting, pain in the arm and shoulder, itching, nasal congestion, lacrimation, salivation, fainting, and spasm of the glottis. Patients who suffer from any sort of allergic manifestations like asthma, hay fever, migraine, and reaction to drugs and foods, particularly to iodine compounds, are thought to be particularly sensitive. It is wise always to question patients about such sensitivities. Reactions have been reported after the use of pitressin for the elimination of intestinal gas. Other contraindications to the use of iodine preparations for intravenous urography include severe liver disorders, nephritis, uremia, and the exudative diatheses in children.

Preliminary testing to determine sensitivity to the preparation that is to be used is advisable. Tests that have been advocated include the mouth test, the intradermal test, and the ocular test. In the mouth test, described by Dolan, 2 cubic centimeters of the preparation are placed in the mouth under the tongue, retained for ten minutes and then swallowed. Sensitivity is indicated by tingling

and numbness of the mouth and lips and swelling of the tongue. If no reaction occurs in thirty minutes, the medium may be used. In the intradermal test 0.05 cubic centimeter is injected into the skin of the forearm making a wheal 2 to 4 millimeters in diameter. If at the end of ten to fifteen minutes a wheal over 10 millimeters in diameter with pseudopodia and erythema has developed, the reaction is considered strongly positive.

In the ocular test, after both eyes have first been examined for comparison, a drop of the iodine preparation is placed in one eye, and the lids are then closed for one and a half minutes as in sleep. Both eyes are examined at the end of one and a half and three and a half minutes. The amount of injection of the conjunctiva and sclera is taken to indicate the severity of the reaction. The positive reactions are divided into minimal, moderate, and marked injection of the conjunctiva and sclera. In minimal reactions the patient will have none or only slight untoward symptoms from the intravenous injection. Those with moderate reactions may have nausea, vomiting, generalized pruritis, urticaria, and swelling of the respiratory membrane. These are transitory and are relieved by the subcutaneous injection of epinephrine. A severe ocular reaction, with the vessels engorged from the iris to the periphery, is a positive contraindication to the use of the preparation being tested.

The milder reactions usually are promptly relieved by the intramuscular injection of 0.3 to 0.5 cubic centimeter of 1 to 1000 epinephrine. This preparation should be kept handy during every injection.

Irrespective of the preparation used for the injection, the examination should be made in the same way. The substances are supplied in sterile ampoules or rubber-capped vials. The injection is made into a vein at the bend of the elbow, using a glass syringe and a small needle. Five to six minutes should be used in the injection.

To prevent the emptying of the ureters and kidney pelves, compression over the lower parts of the ureters is advisable. This may be done with a small hollow rubber ball the size of a grapefruit, or about 4 inches in diameter, under the compression band. Hodges uses a bed sheet rolled into a tight bundle just large enough to fit above the symphysis, over the promontory of the sacrum, and between the iliac crests. An inflated bag is placed over the sheet under the compression band. Stewart uses two small balls made of balsa wood. We have used with satisfactory results two balls about the size of baseballs, with a cover made like that of a baseball, and tightly stuffed with cotton. These are placed over the lower parts of the ureters under the compression band of a Potter-Bucky diaphragm, and as much pressure is applied as the patient will tolerate.

A small non-opaque feather pillow under the sacrum relieves some of the discomfort from the pressure of the bones against the hard table top.

The compression band of the Potter-Bucky diaphragm should be carefully applied. All the pressure should be against the compressing devices, care being taken that none of it is against the pubic or iliac bones of the pelvis. We have found that two or three folded towels over the cotton balls and the use of a narrow compression band (4 inches in width) accomplish this satisfactorily.

Fourteen- by 17-inch films with their long axes in the center of the body are used for all exposures. A Potter-Bucky diaphragm is used.

Sometimes several roentgenograms are required for a satisfactory examination. The first film should be exposed five to eight minutes after the injection is completed. The drug is excreted rapidly by normal kidneys, and the best filling of the pelves and ureters may be obtained at this time. The first film should be developed immediately and the rapidity of excretion determined by its examination. If the patient has been dehydrated and the injection slowly made, the best filling usually will be obtained in fifteen to thirty minutes. If there be a diminished kidney function or obstruction, the best films may be obtained after a much longer interval; sometimes as long as two and three hours are required. To show the lower ureters and the bladder, the last film should be taken immediately after the compression has been removed.

The following is the technique given by Braasch for examination of the urinary bladder by means of cystography: The bladder is filled through a catheter and the catheter withdrawn. A 5 per cent emulsion of silver iodide, a 2 per cent solution of sodium iodide, or a solution of one of the preparations used for intravenous urography should be used. The table is tilted at an angle of 10 degrees toward the feet. The *x*-ray tube also is tilted 5 degrees toward the feet of the patient, making the angle of the incident rays 15 degrees in all. The tube also is tilted laterally 8 degrees and centered so that the rays pass tangentially along the side of the bladder, entering anteriorly and passing medially as well as downward. Two films are exposed in this way, one of each side of the bladder. The catheter then is reintroduced and as much of the solution as possible is removed. In emptying, pressure should not be made with the hand on the abdomen over the bladder. When emptied, the third film is taken. This is an antero-posterior view maintaining the downward tilt of the table and tube but without the lateral angulation of 8 degrees. Compression should not be used with any of these exposures.

Cystography can also be done by filling the urinary bladder with

air. Because opaque filling may obscure small growths, this sometimes is the preferred method. Pfahler is the chief advocate of pneumocystography. The patient is placed supine on a Potter-Bucky diaphragm, the urethra is cleansed, as large a catheter as the urethra will take is introduced, and all the residual urine is removed. A rectal tube is passed into the rectum, the gas removed, and the tube withdrawn. With an atomizer bulb air is gently injected into the bladder until the patient complains of a desire to urinate or until percussion indicates that the bladder is distended. To remove as much residual urine as possible, the bladder is filled and the air allowed to escape two or three times. The catheter is clamped and fastened to the thigh with adhesive tape.

With the bladder filled and the central rays from the tube directed downward and backward, 8- by 10-inch films are exposed. The catheter is held in place and the patient turned to the prone position. Additional films are exposed with the rays directed obliquely upward and forward to project the neck of the bladder clear of the pubic bone. Stereoscopic films in this position are advantageous. Right and left anterior oblique films complete the examination. The catheter is then removed. Eight- by 10-inch films are large enough for all these exposures. Because of the diminished density of the air, the intensity of the exposures should be less than for other exposures through this region.

It is possible to make a double-contrast cystographic examination by the use of umbrathor, a 25 per cent thorium dioxide solution. Determine the bladder capacity either by withdrawing the urine or by use of boric acid solution. Inject a similar amount of umbrathor diluted half with water. About 50 cubic centimeters usually is required. Make immediate exposures for an opaque cystogram. After a ten-minute wait, drain out the umbrathor and replace with air, using two-thirds the quantity that was withdrawn. Make additional exposures. During the waiting period the umbrathor has deposited on the bladder wall as a flocculent precipitate. This, with the injected air, gives a double-contrast cystogram.

In urethrography antero-posterior and oblique films are taken while the urethra is distended with opaque material. Urethrography may be combined with cystography, films being exposed during discharge of the opaque material used in cystography, or exposures may be made while the urethra is distended with injected material. A combined examination with air in the bladder and opaque material in the urethra also is possible. The oblique position, with the patient rotated either to the right or to the left for 30 to 40 degrees and with the penis extended parallel with the thigh, is perhaps best for such exposures. Iodized oil preparations either undiluted or diluted half with sterile olive oil, or one of the iodine

preparations for intravenous urography, are used for injecting the urethra. Flocks described a method of combining iodized oil with gum tragacanth to make a jelly, and Hyams used equal parts of a 20 per cent skiodan solution and a solution consisting of 17.5 per cent iodide, 2 per cent sodium bicarbonate, and 1 per cent gelatin for injecting the urethra. Eight- by 10-inch films are suitable for urethrography, while 10- by 12-inch films are required for a combined examination of the bladder and the urethra.

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CHAPTER XXI.

MISCELLANEOUS EXAMINATIONS.

LOCALIZATION OF FOREIGN BODIES.

In wartime roentgenology the localization of foreign bodies makes up one of the major duties of roentgenologists and demands methods and apparatus for the rapid and accurate performance of this work. Such methods and apparatus are described in special manuals issued by the Medical Departments of the Army and Navy and do not properly come within the scope of this book. Except possibly in connection with a few industries, the civil roentgenologist only occasionally is asked to make an accurate localization of metallic substances in the body. Pieces of needles and small fragments of metal in the extremities, bullets in gunshot injuries, and metallic foreign substances in the eyes are the more common metallic bodies the roentgenologist is requested to locate. For such examinations as are made in the average *x*-ray laboratory, special apparatus rarely is necessary, it being possible to make sufficiently accurate localizations with the usual fluoroscopic and roentgenographic equipment.

An examination for the localization of a foreign body usually should be begun with a preliminary fluoroscopy. Since bullets often take an unexpected path in the body, are frequently found at a distance from their place of entry, and occasionally break up into two or more fragments, this is particularly important in gunshot injuries. For pieces of needles or small bits of metal in the extremities, the fluoroscopy is not so important, for such substances rarely travel far from their place of entrance.

During the fluoroscopic examination, by rotating the patient or the extremity, by making observations at right angles to each other, by finding the position which shows the object nearest the skin surface and estimating its depth, by marking on the skin either the point nearest which the object is located, or two points, one in an anteroposterior and the other in a lateral direction projections from which would cross at the location of the object, by observing the movements caused by palpation over it, and by determining the position with reference to parts of bones or other landmarks, it often is possible to make a very accurate statement of the position of the foreign body from the fluoroscopic examination alone.

To obtain a permanent record of the position of the body for the

use of the surgeon should he wish to attempt its removal, roentgenograms should be made. Two views should be taken which are as nearly as possible at right angles to each other, one to show the position in an antero-posterior plane and the other to show its location in a lateral plane (Fig. 193). In reporting on these films it is important to state the positions of the patient when the films were exposed; it is also important to include the fluoroscopic findings and an accurate anatomical location of the foreign body.

Should it be advisable to determine the exact depth of the foreign body, this may be done by making a double exposure on a single

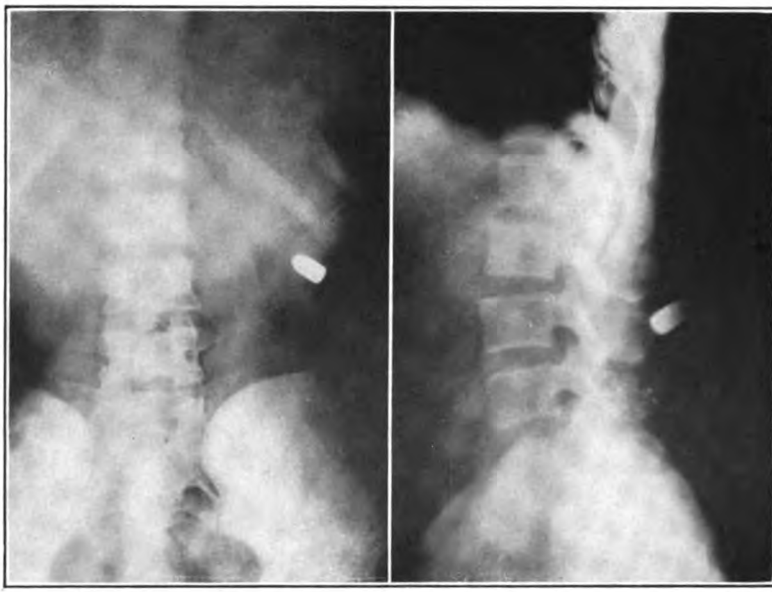

FIG. 193.—Antero-posterior and lateral roentgenograms of a gunshot injury of the back. The bullet entered on the right side, passed through the spinous process of the fourth lumbar vertebra and lodged in the soft tissues. From these films the bullet could be located so accurately that its removal was easy.

film, using a definite procedure which permits of a calculation of the depth of the object. First make a fluoroscopic examination and find the point on the skin nearest the foreign body. Make a mark directly over it and determine the position of the patient which places it nearest the fluoroscopic screen. Then place the patient in a similar position for the exposure, substituting the cassette and film for the screen, with the cassette in direct contact with the patient's body. Place the tube directly over the foreign body, accurately measure the distance from the cassette to the tube anode, make an exposure of about one-half the normal for that region,

shift the tube a known distance along the arms of the tube stand, and make a second exposure similar to the first. The patient must remain immobile from the beginning of the first to the end of the second exposure, and, if the object be in the thorax or abdomen, must suspend respiration during that time. When developed, a film exposed in this manner will show two images of the foreign body.

By using the known anode-film distance, the length of the tube shift, and determining from the film the distance between identical points of the images of the foreign body, enough figures are obtained to make an accurate calculation of the depth of the body from the skin surface. This calculation is based on the fact that the tube shift, the projection of the rays through the body for the two exposures, and the distance between the two images on the film make two similar right-angle triangles, the sum of the heights of which is the known anode-film distance (Fig. 194).

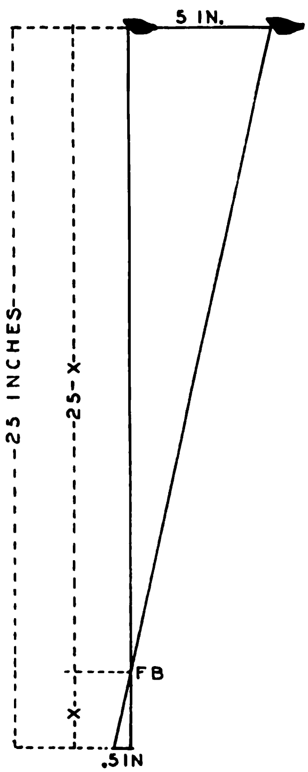

Fig. 194.—Diagram illustrating the method of determining the depth of a foreign body by means of a double exposure, as described in the text. FB, foreign body.

For example, in a case in which the anode-film distance is 25 inches, the tube shift is 5 inches, and the distance between identical parts of the two images is 0.5 inch, the following is a method of determining the depth of the body. This calculation is based on the fact that parts of similar right-angle triangles are proportionate to each other. It will be seen from Fig. 194 that two similar triangles are formed. The height of both is 25 inches, the height of the smaller is represented by x, and that of the larger by $25\text{-}x$. The base of the larger is 5 inches; that of the smaller is 0.5 inch. From these figures the following proportion is obtained.

$25\text{-}x:5::x:0.5$, multiplying the means and the extremes gives

$5x = 12.5 - 0.5x$, changing the sign of the $-0.5x$ and transposing it to the other side of the equation gives

$5.5x = 12.5$, or $x = \dfrac{12.5}{5.5}$ or $x = 2.27$ which is the depth in inches of the body from the skin.

The same result will be obtained by using the following formula which is given by Case. Depth $= \frac{b \times h}{a + b}$, when a is the distance the tube is shifted, h the distance between the screen or film and the anode of the tube, and b the distance of the shift of the shadow of the projectile or foreign body. Substituting in this formula gives depth $= \frac{0.5 \times 25}{5 + 0.5}$ or $\frac{12.5}{5.5}$ or 2.27 inches.

Fluoroscopy is of considerable value in the removal of foreign bodies, the roentgenologist or technician often being called upon to assist the surgeon in such work. First the location of the body is determined by fluoroscopic examination and the skin surface nearest to it is found. To assist the surgeon in making the skin incision, a mark is made directly over the foreign body. Ink, mercurochrome, tincture of iodine, or silver nitrate reduced with a drop of developer (as suggested by Holmes and Ruggles) may be used for this purpose. In the removal of a piece of needle, when possible the mark and the skin incision should be made at right angles to the foreign body. The room lights then may be turned on and the skin incision made, the x-ray worker keeping the eyes protected to preserve the accommodation for further fluoroscopy. If the preliminary search be unsuccessful, a fine pointed curved hemostat then may be introduced into the wound and the fluoroscopy continued. By moving the hemostat from side to side and observing the movements of the foreign body, by increasing or decreasing the depth of the hemostat in the wound, and by rotating the part to permit of observations at different angles, the body can be approached and grasped with the hemostat. Since the proper accommodation of his eyes has been preserved and since he is accustomed to fluoroscopic observations, this usually can be done better by the roentgenologist than by the surgeon. When once grasped, the removal of the foreign body is a simple procedure.

Occasionally a roentgenologist is asked to locate a foreign body in the air passages or in the alimentary canal. If the substance be of a metallic nature, little difficulty should be experienced. By fluoroscopy in different positions and by postero-anterior and lateral roentgenograms, metallic foreign bodies in the air passages can be located. A body, such as a pin or coin, in the alimentary canal can be located by administering a barium meal and finding its position with reference to the barium as it passes through the canal.

Roentgenologic examination is of considerable value in determining the presence of nonopaque substances in the air passages and in the esophagus, but it is not of much value in the rest of the alimentary canal unless the body be of rather large size. In the air

passages a nonopaque substance will cause an obstructive emphysema, a lung abscess, or a complete obstruction with an area of massive collapse in the lung supplied by the obstructed bronchus. Because the inspiratory effort is greater than the expiratory, if the obstruction from a nonopaque foreign body be incomplete, an obstructive emphysema will result in a part of one lung, in an entire lung, or in both lungs, depending on whether the body be in a smaller bronchus, a main bronchus, or in the trachea. In this condition the emphysematous lung tissue will be larger than normal in volume causing changes from normal in the position of the diaphragm and mediastinum, and when there is an emphysema of both lungs from a body in the trachea, a reversal of the normal in the respiratory changes in the size of the heart shadow. These changes have been observed and described by Manges.

The roentgenologic examination for a nonopaque foreign body in the air passages consists of fluoroscopy and the exposure of antero-posterior or postero-anterior films, one at the end of expiration and one at the end of inspiration. The fluoroscopic and roentgenographic images are studied for the changes indicated above.

In examining for nonopaque foreign bodies lodged in the esophagus, Manges recommends observations during the drinking of bismuth and barium mixtures and during the swallowing of gelatin capsules filled with bismuth subcarbonate. Capsules increasing from smaller to the 00 size may be used. Interference with the passage of the capsules and coating of the body with bismuth after dissolution of the gelatin, as seen on the fluoroscopic screen and on antero-posterior and lateral roentgenograms, assist in determining the size, shape, location, and nature of the foreign material.

The accurate localization of foreign bodies in the eyeball requires a Sweet-Bowen apparatus, which should be part of an *x*-ray equipment where much such work is done. The directions for the use of this apparatus accompany it or can be obtained from the United States Army *X*-ray Manual, making it unnecessary to give them here. By careful examinations valuable though not absolutely accurate information can be obtained in those rare cases of foreign bodies in the eye that come to everyone doing roentgenologic work.

It first is necessary to determine whether a foreign body actually is located within the eyeball; some of those that enter through the cornea pass entirely through the globe and lodge in the orbit. The preliminary examination may be made with the fluoroscope or by exposing a film. If the body be large enough to be seen with the fluoroscope and it moves from side to side or up and down with the movements of the eye, the exposures for its localization may be

made. If it cannot be seen with the fluoroscope, films must be taken.

Film exposures are made in the following manner: First take a thin strip of lead rubber, sheet lead, lead foil, malleable wire, or other radiopaque material about 1 inch in length and fasten it with small strips of adhesive plaster to the eyelid of the injured side in a vertical position over the cornea. A small piece of the same material may be fastened vertically to the middle of the strip and placed as nearly as possible directly over the pupil which is located $\frac{1}{8}$ to $\frac{1}{4}$ inch above the margin of the upper eyelid when the eyelids are

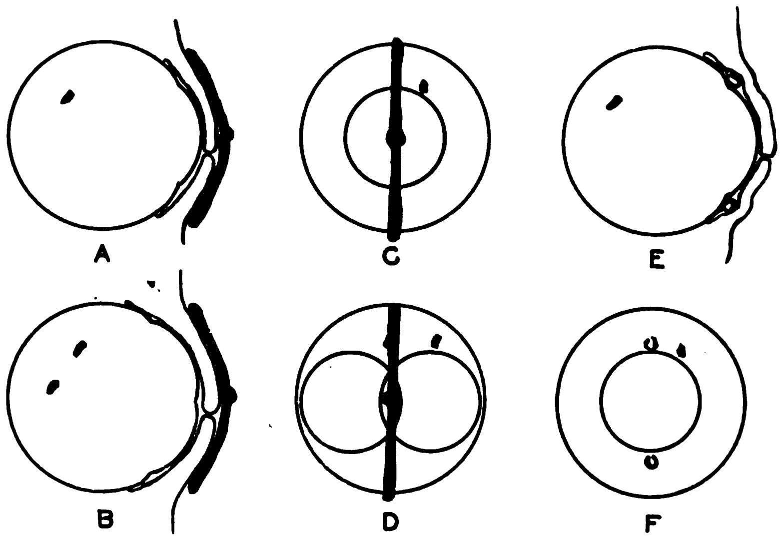

Fig. 195.—Schematic drawings illustrating the methods of localizing metallic foreign bodies in the eye. A, lateral view with an opaque strip on the eyelids; B, double exposure on a lateral view with an opaque strip on the eyelids; C, postero-anterior view similar to A and B; D, double postero-anterior exposure with opaque strip on the eyelids; E and F, lateral and postero-anterior views with contact localizers attached to the conjunctiva as suggested by Patton.

closed. Place the patient in the lateral position on the table with the sagittal plane of the head parallel with the table top (see Fig. 122) with the injured eye down and with the uncovered half of a small cassette under the orbits, the other half being covered with sheet lead or lead rubber. Focus the tube with the central rays passing directly through the orbits and make an exposure with the patient looking with the uninjured eye at an object of the same height as the eye and directly in front of it (Fig. 195, A). Change the cassette so that the unexposed portion is under the orbits with the exposed portion protected. Have the patient look at an object at the same level as the eyes but above his head and make one-half

a full exposure. Without moving the position of the head, then have him look at an object below the level of the eyes and make another half exposure on the same film (Fig. 195, B).

Similar exposures may then be made in a postero-anterior direction, one with the patient looking toward the floor, and a second double exposure with the patient looking first toward the right and then toward the left (Fig. 195, C and D). A position similar to that of the Caldwell position for nasal accessory sinuses (page 330), except that the rays should be directed through the orbit, is about correct for such exposures.

When developed, examination of films exposed in this manner will give a good idea of the location of a metallic foreign body within the orbit. If there be a double image on the double exposures, it is in the eyeball or some other orbital structure that moves with the eyeball. Since the globe of the eye moves within the fascia bulbi (capsule of Tenon), without moving the other orbital structures except the muscles, double images would be nearly positive proof of the presence of the body in the eyeball. By allowing from 2 to 4 millimeters for the thickness of the eyelid and measuring the distance of the shadow behind that of the opaque strip on the lateral views, the approximate depth of the foreign body can be determined. From the postero-anterior views and from the arcs of a circle made by the foreign body on the double exposures, the location of the body with reference to the quadrants of the eyeball, the anterior and posterior hemispheres, etc., may be determined.

A more accurate method of localization that does not require accessory apparatus has been described by Patton. This is by means of contact localizers attached to the conjunctiva of the eyeball near the upper and lower corneal margins. Patton says that the objection to the use of other methods of localization is that there is no way of checking the position of the eyeball at the instant of exposure if the globe may move independently of the opaque marker.

He suggests that the opaque localizers, in the form of small rings, 2 millimeters in diameter, be made by bending No. 26 soft silver suture wire around the points of small tissue forceps and cutting it off with scissors, leaving the rings open. After cocainization of the conjunctiva, it is grasped about 3 millimeters from the margin of the cornea and the rings applied, one above and one below the pupil, by clamping them over the conjunctival folds between the forceps and the corneal margin. A piece of silver wire or sliver of sheet lead clamped around a fine silk suture will serve the same purpose, if the suture be passed through the conjunctiva as near the corneal margin as possible and tied so that the marker is in contact with the conjunctiva. Markers of this kind can easily be removed

by cutting the ring or the suture, the slight corneal trauma being of no consequence. Roentgenograms should be made in the postero-anterior and lateral positions with the markers in place (Fig. 195, E and F). By measuring from the shadows of the markers to those of the foreign body in the two views an accurate localization of the position of the latter may be made. Patton recommends that contact localizers be used with the Sweet-Bowen apparatus to make certain that the eyeball is in the correct position at the time of the exposures.

Pfeiffer has perfected a contact lens made of plastic material on which there are four radiopaque markers separated by arcs of 90 degrees. After anesthetizing the conjunctiva and cornea, this contact lens is placed under the eyelids and the lids closed over it. Lateral and postero-anterior films are then exposed. The apparatus includes a double cassette-holding tunnel, one part holding a film vertically and the other part holding one horizontally. By the use of this tunnel both exposures can be made without changing the position of the patient's head. From measurements made from the films, the position of the foreign body is plotted on a chart prepared for that purpose.

In making measurements of the location of a foreign body within the orbit, it should be remembered that the diameters of the eyeball are from 23 to 24.5 millimeters—slightly less than 1 inch—and that there is a variation of as much as 3 millimeters in the diameters of the eyeballs of different persons.

ROENTGEN-RAY EXAMINATIONS DURING PREGNANCY.

It has been said that the demonstration of the shadows of fetal bones on roentgenograms is the earliest demonstrable positive sign of pregnancy. Fetal bones have been shown as early as the twelfth and thirteenth weeks of a normal pregnancy; they often are shown by the end of the sixteenth week, and they should be shown with but few failures during the twentieth week and thereafter. In addition to the diagnosis of pregnancy, *x*-ray examinations may be used in the determination of the position and the age of the fetus, to diagnose multiple and abnormal pregnancies, to determine fetal death, to locate the placenta, and to measure the size of the maternal pelvis and the fetal head.

Films made for the purpose of diagnosing pregnancy, particularly if early in its course, should be of the very best quality showing a considerable amount of detail and contrast. The patient should be prepared for the examination by the administration of one or more enemas to rid the rectum and pelvic colon of gas and fecal

material, and the bladder should be emptied. A Potter-Bucky diaphragm should always be used. The suspension of respiration during exposures is essential. Various positions have been used for the exposure of the films. Direct postero-anterior, antero-posterior, and oblique exposures with the rays directed from above or from below in the sagittal plane have been used. On films made in the direct postero-anterior or antero-posterior projections, the shadows of the sacrum and the fifth lumbar vertebræ are apt to obscure those of the uterus and its contents. To overcome this objection, Stein and Arens recommend a dorsal posture with an increased lordosis produced by placing sand bags or pillows under the lumbar spine. The rays are directed from above downward in the axis of the superior strait. To have the superior pelvic strait parallel with the film, Thoms in roentgen pelvimetry locates the strait by means of a plane extending from the upper and anterior border of the symphysis pubis to the space between the fourth and fifth lumbar vertebræ posteriorly. The central rays are directed into the pelvis 5 centimeters posterior to the upper border of the symphysis. An oblique exposure from below upward may be made by using the technique described for films of the bladder in the prone position (see page 427 and Fig. 191). As in other examinations more reliable conclusions follow the study of several films exposed with the patient in different positions. Probably the most constant and important finding on films early in pregnancy is the shadows of the centers of ossification for the bodies of the vertebræ appearing in a curved row not unlike a short string of small beads.

Films made in the later months of pregnancy for purposes other than the measurements of the pelvis or the fetal head may be exposed with the patient in the prone, supine, or either lateral position. At least two exposures are required. Since the fetus will be nearer the film in the prone position, this is the better of the antero-posterior positions. For this exposure a folded pad or pillow may be placed under the thighs and under the thorax, thus supporting the weight in a manner that does not compress the abdomen. A direct antero-posterior exposure with the patient supine is about as satisfactory. For the lateral film the patient is placed in either lateral position (Fig. 196). The patient should be prepared for these examinations by one or more cleansing enemas to remove gas and fecal material from the colon. It is important that the patient suspend respiration during the exposures. If the patient rapidly inhales and exhales three or four times before the suspension is begun, it may prevent movements of the fetus from decreased oxygen supply. A Potter-Bucky diaphragm is always used, and

14- by 17-inch films are used with the long axis of the film parallel with the long axis of the body.

In a high percentage of patients the placenta is implanted on the anterior or posterior flat surface of the uterus, extending downward from the fundus and near term covering about a third of the wall of the uterus. The small parts of the fetus usually face the placenta. On a properly exposed film, usually the lateral view, in a majority of instances it is possible to identify and locate the placenta. If a placenta previa be suspected, air injected into the bladder and the rectum in 200-cubic centimeter amounts before the exposures are made will assist in soft tissue differentiation of the lower uterine

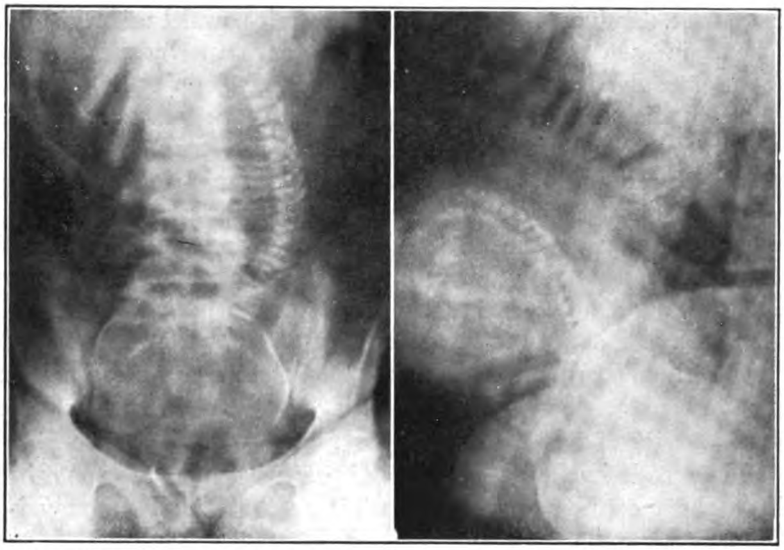

FIG. 196.—Postero-anterior and right lateral views of a pregnant woman near term to determine the position of the fetus. In this case the position is occiput left posterior.

segment. If there be unusual separation of the fetal structures from the bladder, if the placenta cannot be found elsewhere, and if there are no signs of excess amniotic fluid, a placenta previa may be suspected. A false separation of the fetus from the bladder by excess fluid may be eliminated by a lateral exposure with the patient in the erect position.

Mensuration of the female pelvis and the fetal head can be done more accurately by x-ray examinations than by any other method. In general, two classes of procedure are advocated for this purpose. In one the measurements are made with a special stereoroentgenometer as described by Johnson, or with a precision stereoscope from an especially exposed pair of stereoscopic films. In the other,

antero-posterior and lateral films are exposed with a measured anode-film distance. Measurements from these films are taken and corrected for enlargement due to divergence of the x-rays. The corrections require that the method include a way to obtain the distance from the part being measured to the films. A general idea of some of these methods of examination can be given, but the subject is too large for full treatment. For the details the original articles and monographs should be consulted.

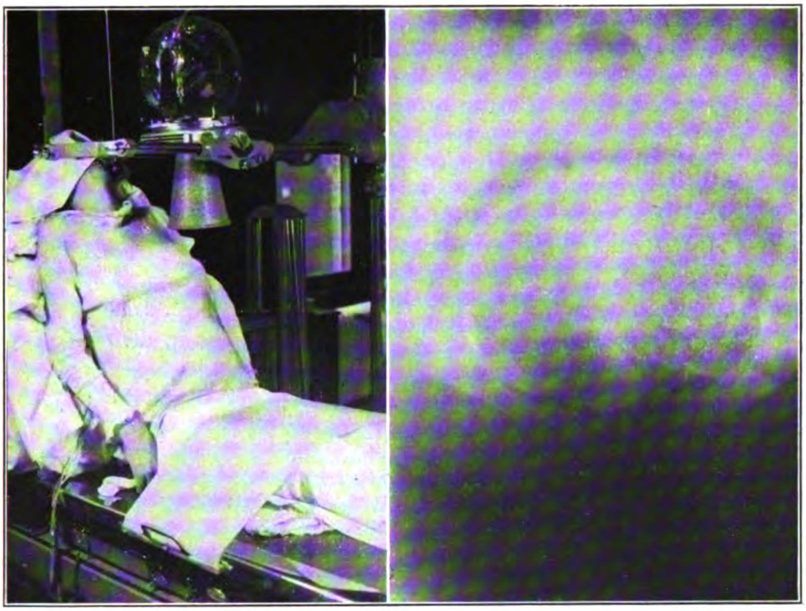

FIG. 197.—Supero-inferior exposure of the superior strait or inlet of the pelvis in roentgenographic pelvimetry.

The inlet of the pelvis lies in a plane connecting the upper border of the symphysis pubis with the space between the fourth and fifth lumbar vertebræ. By placing a narrow strip of adhesive tape between the spinous processes of these two vertebræ, both these landmarks can be used in placing the patient on the table. The patient should be in a semisitting posture supported on a backrest. The lumbar curve of the spine is exaggerated and the pelvis tilted forward. If the feet be placed against a rigid support or a compression band stretched across the thighs (Fig. 197), the position can be maintained.

To determine the tilting of the pelvis required to bring the inlet parallel with the film, Ewer and Bowen use a pelvimeter to which a spirit level has been attached. One tip of the pelvimeter is placed

at the top of the pubis, the other over the adhesive strip on the patient's back. They use a plumb bob suspended below the focal spot of the tube to center the rays over the midpoint of a line connecting the anterior superior iliac spines.

In the exposure a Potter-Bucky diaphragm is used. The distance of the anode of the tube to the film, that from the pelvimeter to the table top, and that from the table top to the film in the diaphragm tray must be carefully measured.

When the film has been developed, the diameters of the pelvis are determined by substituting in the following proportion: x: a :: b-c : b, when x is the unknown pelvic diameter, a is the measurement of the diameter as obtained from the film, b is the distance of the anode of the tube from the *x*-ray film, and c is the distance of the pelvimeter from the film. A formula derived from this proportion is $x = a \frac{(b-c)}{b}$. This method has the advantage in that the pelvimeter and the plumb bob are the only accessory apparatus required.

Methods have been devised for taking the measurements directly from the films without a mathematical calculation. These include the use of a perforated grid as perfected by Thoms in which there are small holes 1 centimeter apart. After a film has been exposed as described, the patient is removed without disturbing the film or tube, the grid is placed over the film in the position of the pelvic inlet, and a flash exposure is made. This registers the small holes on the films with the same distortion as the pelvis. A special apparatus for Thoms' pelvimetry has been made and marketed by Torpin. On the films the diameters of the pelvis are read directly by means of the centimeter scale impressed on the film by the grid. In many instances it is possible to determine the occipitofrontal dimensions of the fetal head in the same manner.

Other method of making direct measurements from the film include the use of a set of scales made by roentgenographing a steel ruler at varying distances above the table top as described by McNeill. These scales are used in making measurements directly from films of the pelvis, the scale used for each measurement being the one exposed the same distance from the film as the pelvic part being measured. In this way the distortion of the scale and the part are the same so that the measurement may be read directly.

In one of his latest reports, Thoms describes a method of making a film obliquely from above downward as described above, and a lateral film of the pelvis with the patient in the erect position. This article describes a special roentgen pelvimeter by the use of which measurements of the pelvis are taken directly from the films, correction being made for distortion.

Snow has perfected a slide rule for roentgen pelvimetry and described a method of making roentgenograms of the pelvis with which it is used. Four films are exposed. One of these is taken in the usual antero-posterior position with folded towels or sheets under the small of the back to tilt the pelvic inlet downward. A 14- by 17-inch film is used with the long axis transverse. To include all the important structures on the film, the patient is placed with the upper border of the symphysis pubis even with the junction of the middle and inferior thirds of the film. The heels and toes should be close together. A 30-inch anode-film distance is used (A, Fig. 198). The second of the four films is oblique from below upward through the subpubic angle. The angulation is not exact and may be as much as 40 degrees.

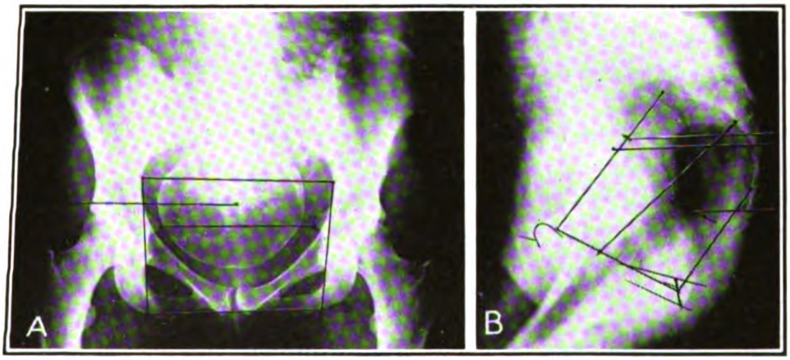

FIG. 198.—Films of the pelvis for pelvimetry exposed by the method described by Snow. A, antero-posterior film exposed with the patient supine and with a folded sheet under the lumbar spine tilting the pelvis downward. B, lateral film of the pelvis exposed with the patient in the lateral position and with the rays centered through the greater trochanters of the femora.

The third view is in the lateral direction. The patient is placed as nearly as possible in the lateral position. The directions for this are the same as for the lateral view of the lumbar spine and lumbosacral joint (see p. 282). The 14- by 17-inch film is placed with the long axis parallel with the long axis of the body. The inferior border of the film must be at the level of the gluteal fold, and the superior border must extend above the iliac crests. The tube is centered so that the central rays will pass through both greater trochanters of the femora. The anode-film distance is 30 inches. There is great depth of tissue in this position requiring a long, heavy-intensity exposure. It is better for there to be over- rather than under exposure (B, Fig. 198).

The fourth film is also made in the lateral position but at a higher level. A 14- by 17-inch film is placed longitudinally, and

the patient placed with the fundus and anterior border of the uterus all included on the film. The exposure of this film should be such as to show best the soft tissues of the fetus and the uterus.

From measurements taken from these films and corrected for distortion by the use of a slide rule or from a table showing the distorted measurements at different distances from the film, it is possible to determine accurate pelvic and fetal measurements.

THE EXAMINATION OF DISCHARGING SINUSES.

Patients who have had gall bladder and other drainage operations and those who have suppurative disease around the rectum, in the groin, extending down the psoas muscles from the vertebræ or perirenal tissues, or coming from bones, occasionally have persistent discharging sinuses. It is important that the origin, direction, and extent of these be determined before operative measures for their permanent cure are undertaken. By examining these sinuses filled with radiopaque substances, this information can be obtained.

Various preparations have been used for this purpose, the opacity to Roentgen-rays of all of them being produced by barium sulphate, bismuth, iodine, or bromine in some form contained in them. Beck's bismuth paste probably is the oldest and best known of such preparations. Schanz describes three preparations containing sodium bromide or iodide in a mixture containing either corn starch, Irish moss, or tragacanth and glycerin, with 0.5 per cent phenol added as a preservative. MacLeod recommends an emulsion of 1 part of oxychloride of bismuth and 2 parts mucilage of acacia. A useful liquid preparation of sodium iodide consists of a 12 per cent solution containing mercuric iodide in a strength of 1 to 3000 to render the solution sterile and mildly antiseptic. More recently the iodized oil preparations such as lipiodol and iodopin have been introduced.

Beck's paste must be injected while heated, it does not mix with pus or tissue débris, it cannot be washed out of sinus tracts or cavities, often being retained for weeks, and in earlier days cases of poisoning from it were reported. Its retention makes it possible to make examinations in more than one position without danger of its running out. Since it has distinct antiseptic properties and is used in treatment, its particular field of usefulness is in injecting sinuses springing from bones and joints. The preparations described by Schanz and MacLeod are of such consistency that they are well retained during the examinations and, being water soluble, they can be washed out by irrigating with saline solution. The sodium iodide solution is most useful in pyelography and in inecjting sinuses springing from the viscera, for example one connected with the gall

bladder and biliary tract. It has the disadvantage of running out of the sinus when the position of the patient is changed, so that if the opening cannot be closed, all exposures must be made with it uppermost. The iodized oils have the same objections as the iodide solution, and in addition are too expensive for the injection of any but small sinuses or spaces.

The method of preparation of bismuth paste as given by Beck is as follows:

"Bismuth paste is a 10 per cent mixture, 1 part of bismuth subnitrate to 9 parts of vaseline. The mixing bowls, jars, and spoon are sterilized. The vaseline is sterilized by heating for twenty minutes if not in the original container. The bismuth subnitrate is sterile in sealed cans when it comes from the manufacturer and so does not have to be resterilized. The mixing bowls and jars must be absolutely dry, as the slightest amount of water produces a curdling of the paste and it is then useless.

"The bismuth subnitrate is poured into the mixing bowl and all lumps smoothed out with the spoon. Sufficient amount of vaseline, which is still in the liquid condition from the sterilizing, is poured slowly into the bismuth, to make a stiff paste. This mixture is then stirred for an hour until it is a smooth, bright yellow, homogeneous paste.

"To the balance of the nine parts of the liquefied vaseline which has been heated to liquefaction, this mixture of thick paste is gradually added, stirring it constantly. The resulting product should be a light yellow, smooth, homogeneous paste, which, on cooling, becomes congealed without the precipitation of the bismuth."

The corn starch preparation described by Schanz is made by suspending 10 grams of corn starch in 100 cubic centimeters of water and heating in a water-bath. It is stirred continuously until a thick paste is formed. Sixteen cubic centimeters of glycerin are then mixed in thoroughly. Then either 15 grams of sodium iodide or 25 grams of sodium bromide are added. To preserve the preparation, 0.5 cubic centimeter of phenol or 1 cubic centimeter of oil of thyme is added.

The technique of injecting a discharging sinus is the same with any preparation that is used. If Beck's paste be used, it first is melted in a water-bath and well stirred with a glass rod that has been flamed. The syringe is boiled and must still be quite warm. Other preparations also should be warm when injected. The preparation is drawn into a 10- or 20-cubic centimeter glass syringe, the tip for attaching the needle is introduced into the opening of the sinus, and the injection slowly made. Because pressure can be made with the end of the syringe around the opening to prevent reflux of the

material, a syringe without a cannula or needle usually is satisfactory. If there be more than one opening these must be closed with the fingers as the preparation begins to escape from them. The injection is continued until the patient begins to complain of pressure. When the injection has been completed, the syringe is removed, the excess of the preparation wiped from the skin, and, if possible, all openings closed with strips of adhesive plaster to which have been fastened small pieces of lead so that the position of the openings will be shown on the films.

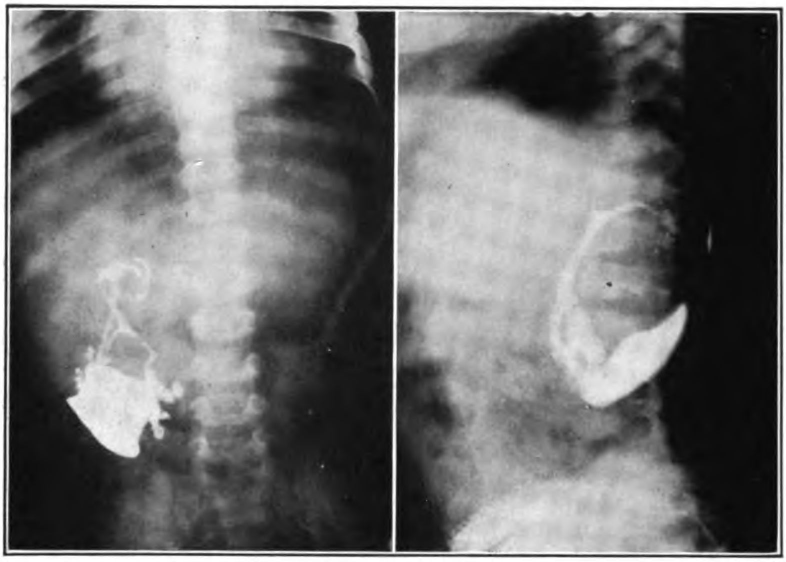

FIG. 199.—An antero-posterior and a right lateral view of an injected sinus tract in a child, originating in the perirenal tissues.

The roentgenography does not differ from that of the same part of the body for any other purpose. If the direction and extent of the sinus be unknown, it is advisable to use rather large films and include a considerable distance both above and below the openings. Whenever possible, stereoscopic films should be taken. If they are not made, two views, at right angles to each other, should be made (Fig. 199). For parts of the trunk or region of the hips a Potter-Bucky diaphragm is essential.

BREAST.

In 1930 Warren presented an article describing a method of studying the breast by means of stereoscopic roentgenograms. Since that time this procedure has been considerably advanced, particularly

by Lockwood, who believes that the roentgen examination of the breast is comparable to the gross examination of excised breast tissue. Diagnoses made from breast roentgenograms by competent examiners have proved accurate in a high percentage of instances.

The technique in making breast roentgenograms is not difficult, the object being to make each exposure with the rays passing tangentially through the side of the thorax and through the breast with its base perpendicular to the film surface. The patient is placed in a semirecumbent or posterior oblique position with the upper extremity abducted from the side at a right angle with the thorax. The hand of this extremity may be placed under the head.

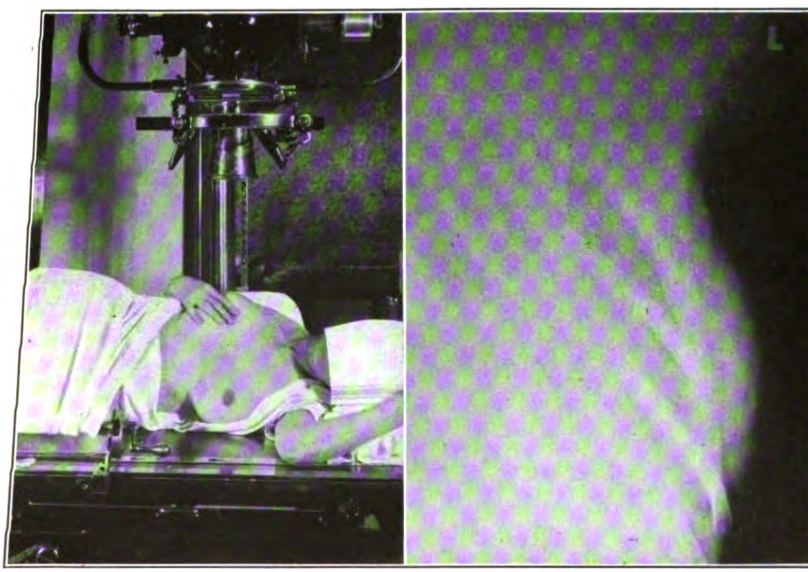

Fig. 200.—Oblique exposure of the breast.

The degree of rotation is such that the breast projects from the side in the shape of a cone with a vertical base. The opposite hand is used in holding the opposite breast out of the way and making traction on the skin of the front of the chest to support in the proper position the breast being examined. The nipple should be shown in profile. Seabold advocates the use of a wire cradle covered with washed gauze to support pendulous breasts. The position of the patient is maintained by placing sand bags or pillows under the back and by the use of a compression band over the pelvis (Fig. 200). For comparison roentgenograms of both breasts always are made.

Single films may be made but stereoscopic films are preferable. The tube shift may be in the longitudinal or transverse direction.

The film area should be large enough to include the breast, the side of the chest wall, and the axillary structures as high as the abducted humerus. Usually two 10- by 12-inch films divided transversely are large enough for stereoscopic exposures of both breasts.

Contrast roentgenograms of the breasts have been made with considerable success. The chief advocates of this procedure are Dickens, Best, Hunt, and Harris. These investigators have injected opaque material into the milk ducts, and have outlined the breast proper by injecting carbon dioxide into the premammary and retromammary connective tissue. Hot moist compresses applied to the nipples for fifteen minutes will open the milk ducts. A small amount of secretion can be expressed from each duct by stripping. The openings are located and injected with a specially constructed needle. From 0.5 to 2 cubic centimeters of opaque material (26 per cent thorotrast) is injected into each duct. Six to eight filled ducts give good visualization of the breast. After stereoscopic films are made, the opaque material is removed with a breast pump and by stripping the nipple.

Carbon dioxide, from a small tank provided with a reducing valve, is run through a flask of sterile water and a piece of rubber tubing to a sharp 20-gauge needle. With the needle introduced behind the breast, the gas is injected until it spreads around the gland. The needle is then removed and re-inserted into the premammary subcutaneous tissue and it, too, is injected. Exposures must be made quickly, for the carbon dioxide is rapidly absorbed.

The films are exposed in a lateral recumbent position with the breast supported on a 17- or 23-degree angle board. The central rays strike the breast in a direct transverse direction. Films in cardboard holders are thought to give better detail than films and intensifying screens.

LARYNX.

Roentgenograms of the larynx show the laryngeal cartilages and the air-containing portions so distinctly that much diagnostic information can be obtained from them. They are of particular value in suspected or proved cases of intrinsic and extrinsic carcinomata in this region.

The technical procedures are much like those for a lateral view of the cervical spine (see page 276). The patient may be sitting sideways in front of a vertical plate holder or supine on the table. If sitting, some method of immobilizing the head should be employed. The cassette is placed parallel with the midline of the neck, projecting from the upper border of the pinna to the region of the shoulder. The shoulders should be depressed as much as possible.

The chin should be held forward; with the patient sitting the mandible should be parallel with the floor; with the patient recumbent the body of the lower jaw should be perpendicular to the table (Fig. 201).

Since the larynx cannot be brought close to the film, to reduce distortion a long anode-film distance should be used; 4 feet is the minimum, 60 to 72 inches is preferable. The central rays should be directed through the midpoint of the thyroid cartilage. A small cone and a limited beam of x-rays are essential for maximum contrast and detail on the films. The films may be exposed with the larynx at rest and during phonation of a high-pitched E. There is less likelihood of blurring by motion during a rapid exposure. Respiration should be suspended. The 8- by 10-inch film is adequate for roentgenograms of the larynx.

FIG. 201.—Exposure of the larynx with the patient sitting. The same position may be used for an exposure of the cervical spine. The position shown in Fig. 108 may be used for exposing a film of the larynx.

SIALOGRAPHY.

By sialography is meant the visualization of the ducts, ductules, and parenchyma of the salivary glands by means of the injection of radiopaque material into the duct system. Because other preparations are not dense enough for this purpose, some form of iodized oil is always used.

The injection is not difficult. The opening of the duct, either the parotid duct in the cheek opposite the upper second molar tooth or the submaxillary in the floor of the mouth under the tongue, is first located. If difficulty be encountered, saliva may be manually expressed or a flow excited by having the patient suck a piece of lemon, and the duct opening located by the salivary flow. The

mucous membrane around the duct is painted with mercurochrome and anesthetized by the topical application of 10 per cent cocaine. If the opening be small it may be necessary to dilate it with a tapered probe. The end of a blunt-pointed 18- or 20-gauge hypodermic needle is inserted into the duct for about 1 centimeter and warmed iodized oil is slowly injected. Some discomfort will be experienced by the patient even before the injection is completed. From 1 to 2 cubic centimeters of oil are required to fill the normal parotid duct; about half this amount for the normal submaxillary duct. Dilated ducts will require a greater quantity.

Lateral stereoscopic films should be made of either duct with the face against the cassette changer or the surface of a vertical or horizontal Potter-Bucky diaphragm. To widen the space behind the mandible as much as possible, for films of the parotid ducts the chin is elevated and the head hyperextended as much as possible. If a tumor be present, an antero-posterior or a postero-anterior film with the rays directed as nearly as possible through the tumor, may give additional information of value.

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